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Central North Corridor Bus Service Study

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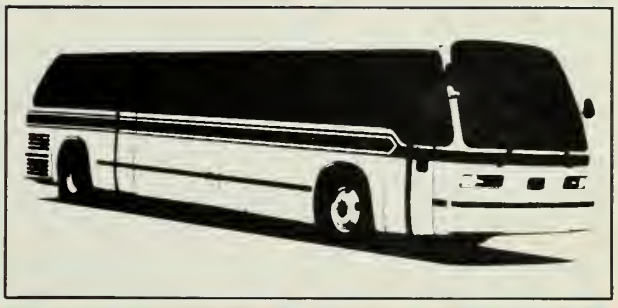
Supplement 1



Produced for the Massachusetts Bay Transportation Authority by the Central Transportation Planning Staff

Central North Corridor

Bus Service Study

Supplement 1

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Central Transportation Planning Staff
An interagency transportation-planning staff created and directed by the Metropolitan Planning Organization, which comprises:

Executive Office of Transportation and Construction
Massachusetts Bay Transportation Authority
Massachusetts Department of Public Works
MBTA Advisory Board
Massachusetts Port Authority
Metropolitan Area Planning Council

July 1988

In this document, which supplements the CTPS report, Central North Corridor: Bus Service Study (July 1988), the ten technical memoranda written over the course of the study are collected (as Appendices A through J). In Supplement 2, the most important of the computer printouts and miscellaneous documents produced during the study are compiled (as Appendices K through O).

TABLE OF CONTENTS

A Data Collection

B Route 70 Analysis

C Bunching of Buses on Brookline Avenue

D Route 47 Unreliability

E Schedule Coordination of Central North Routes

F Route 66 Unreliability

G Bus Route Productivity, Efficiency and Reliability

H Central North Bus Market Analysis

I Kendall Square/Central Square Bus Service

J Somerville/Cambridge Cross-town Routes

APPENDIX A
DATA COLLECTION

CTPS

State Transportation Building
10 Park Plaza, Suite 2150
Boston, MA. 02116-3968
(617) 973-7100

CENTRAL TRANSPORTATION PLANNING STAFF

MEMORANDUM

TO: Central North Bus Study Files May 8, 1985

FROM: Karl H. Quackenbush

RE: Data Collection Phase

The goal of the Central North Bus Study is to derive recommendations for improving service on MBTA local bus routes 1, 47, 57, 60, 63, 64, 65, 66, 69, 70, 83, 85, 86 and 91. The purpose of this memo is to document the data collection phase of the study.

The data collection phase can be divided into three major efforts: ridechecking, on-board surveying and miscellaneous data collection. Each will be described in turn in the following paragraphs. Attachment A contains a summary of resources devoted to, and products resulting from the tasks within each major effort. Attachment B lists direct MBTA costs by task.

I. Ridechecks

Ridechecks were conducted in order to obtain bus running times and counts of boardings and alightings by bus stop. These data will be used to, among other things, construct load profiles, graphs of terminal-to-terminal bus running times, and various performance measures. Most ridecheck-related activities can be grouped according to whether they occurred prior to, during, or after the actual ridechecking.

A. Pre-Ridecheck Activities

1. Field Checks - Each of the 14 study-area bus routes was driven over by a two-person team for the purposes of: verifying the locations of bus stops as listed in MBTA files, documenting landmarks to orient ridecheckers, obtaining the distance between stops measured by automobile odometer, and ascertaining shelter locations.

2. Sampling Plan and Scheduling - A straightforward sampling plan was agreed upon by the MBTA and CTPS. For most routes, close to 100% of the scheduled weekday revenue-trips and two-thirds of the scheduled weekend revenue-trips were included in the sampling plan. On a few routes where headways were quite close (less than 10 minutes), only 75%-85% of scheduled weekday trips were included in the sample.

The resulting sample size conformed roughly to generally accepted standards of accuracy.[1] It allows one to be 90% confident that a route's true weekday boardings within a given time period are within ±10-20% of observed boardings, depending on the time period. Similarly, the sample size implies a tolerance range of ±20-30% for weekend boardings.

Individual checker assignments were constructed by first extracting relevant driver runs from MBTA timetables and headway sheets and then tailoring these runs to conform to such logistical constraints as minimum and maximum allowable ridechecker shifts, break requirements, and ridechecker deployment locations.

Assignments were grouped by time period and deployment location. Each group was then scheduled for a specific day, and one of two supervisors was assigned to oversee it.

The number of assignments developed, by time period, was as follows: early morning/A.M. peak, 65; midday, 50; P.M. peak, 60: night, 24; Saturday, 40; and Sunday, 21. Most early morning/A.M. peak assignments were paired with P.M. peak assignments to form so-called "split shifts", each to be done by one individual.

The majority of assignments were scheduled to begin and end at Central Square, Cambridge, and Kenmore Square. Others were scheduled for Harvard Square, Kendall Square, Lechmere Station, Sullivan Station, Watertown Yard, Boston City Hospital and Union Square, Allston.

3. Personnel Recruitment and Training - Ridecheckers were recruited through TAD, Inc., a temporary employment contractor. An initial pool of 23 individuals was recruited. Also, two individuals were recruited to supervise the ridecheckers in the field.

Ridecheckers and field supervisors were trained in one two-hour session. They were then outfitted with clipboards, maps, instruction sheets, badges, and assignments for the following day.

4. Forms Preparation - Two types of forms were prepared for ridechecking. First, detailed bus stop lists, based on the field checks,were formulated, typed and duplicated. Each

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[1]As reported in Bus Transit Monitoring Manual, Volume 1: Data Collection Program Design, prepared by Multisystems, Inc., and ATE Management & Service Co. for the U. S. DOT (August, 1981).

form, to be used on one one-way trip, contained spaces for recording ons and offs, as well as beginning, intermediate and ending bus trip times. Attachment C consists of a sample bus stop list. Checker assignment sheets, each listing the departure time and place for each trip to be checked, were also produced. Each assignment sheet was eventually put together with the appropriate bus stop lists to form checker assignment packets.

B. Ridechecks and Concurrent Activities

1. Ridechecks - Actual ridechecking was accomplished, as indicated above, by temporary personnel working under the direct supervision of temporary field supervisors. The latter were responsible, in part, for keeping track of ridechecker hours, distributing new assignment packets and collecting completed ones, and ensuring that checkers boarded their assigned bus trips.

Ridechecks of the 14 study-area routes were completed in one month - November, 1984 - with a ridechecker work force that averaged 21 individuals per week, each working an average of 15-25 hours per week. A total of 2,456 one-way bus trips was checked.

2. Daily Deployment and Ridechecker Management - Each day of ridechecking, one CTPS staff person was occupied nearly full time in managing the process. Although scheduling was based generally on a previously established master plan, the actual schedule for a given day was also a function of fluctuating checker availability. Therefore, each day, a roster of assignments to be done the following day was constructed, and ridecheckers from the pool who could work the particular location and time of day were contacted, directly or through field supervisors, and matched with assignments.

Telephone contact was maintained with the field supervisors and, based upon their reports, assignments were modified or cancelled due to either buses or ridecheckers not appearing as expected. In addition, the field supervisors were seen daily in order to exchange new assignment packets for completed ones.

Numerous additional day-to-day activities included recording checker's hours, coordinating with the temporary agency, and substituting at odd hours for the field supervisors. Because some checkers quit or were let go, new checkers were continuously recruited and trained, and toward the end of ridechecking, make-up assignments were constructed.

3. Forms Management - Each day, assignment sheets and bus stop lists were organized into outgoing assignment packets for the following day. Incoming, completed forms were then perused and accounted for to ascertain which trips remained to be counted and which needed to be rescheduled.

C. Post-Ridecheck Activities

1. Data Cleaning and Coding - Three temporary workers were hired for 11 days through ADIA Personnel Services to help prepare the completed ridecheck forms for keypunching. Each form was edited for completeness and clarity, and the numbers of ons and offs on each trip were totalled. CTPS staff subsequently examined the forms on which ons and offs did not balance, and corrected them when the source of error was obvious.

2. Keypunching - Bids were solicited from five firms and the work was awarded to Punch City, Inc., the lowest bidder.

3. Miscellaneous Data Organization - Various data items collected during the field checks, such as distances between bus stops and shelter locations, were edited and organized for use in analysis.

4. Initial Data Processing - The keypunched ridecheck data, consisting of 45,590 records, were entered into the MBTA computer and organized for subsequent computer analysis.

D. Miscellaneous Administration

Tasks in this category do not fit neatly elsewhere. They include writing various letters and memos, attending meetings, recordkeeping and overall coordination of the ridechecking effort.

II. On-Board Survey

A survey questionnaire was administered on-board a sample of study-area bus trips in order to obtain data on passenger socio-economic characteristics, travel behavior and attitudes. Boardings obtained from the ridechecks will be used to expand the survey sample data. These data will then be organized into cross-tabulations and frequency distributions, and used to analyze such things as bus transfer rates, route revenue and origin/destination patterns.

Most survey-related tasks can be grouped according to whether they occurred prior to, during, or after the actual surveying.

A. Pre-survey Activities

1. Sampling Plan and Scheduling - A sampling plan was developed, at a route level, for weekdays and Saturday. It was designed so that one could be 90% confident that a route's rider attributes are within ±5% of the measured weekday values and ±10% of the measured Saturday values. These specifications resulted in from six to 12 of a route's weekday round trips and two to three of a route's Saturday round-trips being included in the sampling plan.

Most surveyor assignments were constructed for a given route or set of routes by first piecing together, from relevant driver runs, the requisite number of sample trips into several different potential assignments, each of which conformed to logistical constraints, and then randomly selecting those assignments that would actually be done. This procedure was employed to help minimize trip selection bias while maximizing efficiency. In many cases, though, logistical constraints alone dictated which trips were sampled.

Assignments were grouped by time period and by the routes comprising them, and then each group was assigned to be done on a specific day. Thirteen A.M. peak/midday, 13 midday/P.M. peak and four strictly midday assignments were developed.

2. Questionnaire Preparation - The questionnaire used in the South Shore Bus Study was modified and improved for use in the Central North Study. A pre-test was then administered on-board a study area bus, resulting in further modifications. Bids were solicited for printing 8,000 questionnaires and the work was done by Sir Speedy, Inc., the lowest bidder. Attachment D consists of a sample questionnaire.

3. Additional Preparation - Temporary personnel requirements for survey distribution were minimal. A pool of four workers was recruited through Kelly Services, Inc., and trained in survey procedures. No field supervisors were employed.

Numerous small preparatory tasks were accomplished. For example, surveyor assignment sheets, listing the specific trips to be sampled, were produced, and procedures for managing returned surveys were established.

B. Surveying and Concurrent Activities

1. Surveying - Surveys were distributed on board buses during the last week of January and the first two weeks of

February, 1985. Weekday surveying occurred between 6:00 A.M. and 7:30 P.M., and was stratified by A.M. peak, midday and P.M. peak. Saturday surveying occurred between 10:00 A.M. and 6:30 P.M.

Surveyors rode on sampled buses and attempted to offer a questionnaire to every boarding individual. The surveyor answered questions and collected completed questionnaires. A mail-back option was provided for people who could not complete the questionnaire on the bus.

A total of 249 weekday and 74 Saturday one-way bus trips was sampled. The questionnaire acceptance rate was in the range of 60 to 65 percent. Of the 6,912 questionnaires distributed, 4,187 were returned, for a response rate of 61 percent.

2. Daily Deployment and Surveyor Management - Each day of surveying, a CTPS staff person met with the surveyors, either in the field or office, in order to collect completed questionnaires, dispense new ones and give the surveyor an assignment for the following day. Phone contact with surveyors was also maintained in order to solve problems (most of which related to buses not appearing as scheduled) and modify assignments as needed.

Additional activities included putting together assignment packets on a daily basis and constructing makeup assignments during the latter part of surveying. Due to surveyor turnover, some extra recruiting and training was necessary.

3. Management of Returned Questionnaires - Much time was spent in organizing incoming returned questionnaires. To facilitate coding, they were sorted by one-way trip and placed in the order they had been distributed. Individual surveyor acceptance and return rates were calculated and recorded, and periodically, groups of questionnaires were examined in order to confirm that surveyors were doing their assignments correctly and completely.

C. Post-survey Activities

1. Questionnaire Cleaning and Coding - Four temporary workers were hired through Harvard Student Agencies, Inc., to prepare questionnaires for keypunching. Each questionnaire was edited for completeness and clarity and then coded. CTPS staff subsequently reviewed each questionnaire to ensure proper coding.

2. Keypunching - Bids were solicited from five firms and the work was awarded to Manassa Systems, Inc., the lowest bidder.

3. Initial Data Processing - The keypunched questionnaire data were entered into the MBTA computer and organized for subsequent computer analysis. The file consists of 3,792 reocrds.

D. Miscellaneous Administration

As with ridechecking, various activities were engaged in throughout the survey process. Letter writing, attending meetings, recordkeeping, and overall coordination are all examples of activities within this category.

III. Miscellaneous Data Collection

Although the ridechecks and on-board survey provided most of the data needed for the project, information was also collected in the areas of bus operations, bus operating costs, and corridor-level demographics and travel characteristics. Bus operations data, consisting of such things as vehicle requirements by route and official route lengths, were obtained from the MBTA, and will be used in conjunction with ridecheck data to develop performance measures. Bus operating costs were also obtained from the MBTA and will be used in conjunction with revenue estimates obtained from the survey data to develop additional performance measures. Demographic and travel information was obtained from the U. S. Census and will be used in the analysis of latent transit demand.

KQ:od:22305

ATTACHMENT A

PRODUCTS AND PERSONNEL REQUIREMENTS BY TASK

Task	Products/Accomplishments	Personnel Requirements (Person-hours) CTPS	Temporary Workers
I. RIDECHECKING			
Field Checks	Provided accurate information for bus stop lists	49	-
Sampling Plan/ Scheduling	Master sampling plan 260 Ridechecker assignments	127	-
Recruitment/ Training	23 trained ridecheckers 2 trained field supervisors	29	50
Forms Preparation	Detailed bus stop lists/ ridecheck forms Checker assignment sheets	62	-
Ridechecks	Ons and offs by stop & bus travel times for 2,456 one-way bus trips	-	2,076
Deployment/Checker Management	Daily assignment rosters Make-up assignments	231	-
Forms Management	Daily assignment packets Accounts of successfully completed trips	122	-
Data Cleaning/ Coding	Edited & coded ridecheck data	242	157
Keypunching	Tape of ridecheck data	10	-
Miscellaneous Data Organization	Lists of stop spacing, shelter locations, stops/mile	38	-
Initial Data Processing	45,590 record file for analysis	21	-
Miscellaneous Administration	Various letters, memos, meetings, accounts	38	-

Task	Products/Accomplishments	Personnel Requirements (Person-hours) CTPS	Temporary Workers
II. ON-BOARD SURVEY			
Sampling Plan/ Scheduling	Master sampling plan 30 surveyor assignments	40	-
Questionnaire Preparation	8,000 questionnaires	49	-
Additional Preparation	4 trained surveyors Assignment sheets Surveyor materials/ equipment	45	8
Surveying	4,187 returned questionnaires	-	210
Deployment/Surveyor Management	Daily assignment roster Assignment packages Make-up assignments	123	-
Incoming Questionnaire Management	Sorted & checked questionnaire bundles Accounts of question-naires by route and time period	125	-
Cleaning/ Coding	Edited & coded questionnaires	348	216
Keypunching	Tape of survey data	9	-
Data Processing-Initial	3,792 record file for analysis	7	-
Miscellaneous Administration	Various letters, memos, meetings, accounts	28	-
III. MISCELLANEOUS DATA COLLECTION	Various lists & tables of supplementary data	30	-

ATTACHMENT B

DIRECT MBTA COSTS BY TASK

Task	Unit Cost	Total Cost
Ridechecking		
Ridechecks	$7.00/hour-ridecheckers $10.00/hour-supervisors	$15,525.88
Data Cleaning	$6.25/hour	982.82
Keypunching	$0.04/record	1,838.60
Subtotal		$18,347.30
On-Board Surveying		
Questionnaire Printing	$0.08/questionnaire	$ 640.00
Questionnaire Distribution	$8.70/hour	1,832.46
Data Cleaning	$9.00/hour	1,926.00
Keypunching	$0.18/record	682.56
Subtotal		$5,081.02
Total		$23,428.32

ATTACHMENT C - SAMPLE BUS STOP LIST

Route Name CENTRAL SQUARE, CAMBRIDGE TO SULLIVAN SQUARE

Date _____ Begin End

Weather _____ Checker _____

Seating Capacity _____

Cash _____

Tokens _____

Pennies _____

Day (Sunday=1)	Route No.	Dir.	Scheduled Time Leave Terminal	Actual Time Leave Terminal	15 -1 am -2 pm
1	91.0 (2)	0 (6)	7	11	

STOP NAME	15 NO.	21 TIME	25 ONS	28 OFFS	31	
River St. @ Western Avenue EOL	2445				01	
Prospect St. @ Bishop Allen Dr.	2446				02	
Prospect St. @ Harvard St.	2447				03	
Prospect St. @ Broadway (No sign)	2448				04	
Prospect St. @ Gardner Road	2449				05	
Prospect St. @ Hampshire St. (Bef inters)	2450				06	
Hampshire St. @ Cambridge (Inman Sq)	2451				07	
#45 Springfield @ Houghton St.	2768				08	
Springfield @ Concord Ave. (By stop sign)	2769				09	
Newton St. @ Webster Ave. (Charlies Auto Sales)	2530				10	
Prospect @ Somerville (Opp. Dunkin Donuts)	2531				11	
Washington @ Merriam St. (Opp. Speedy Muffler King)	2773				12	
Washington @ McGrath Hwy. (Bef overpass, intersection)	2774				13	
Washington St. @ McGrath Hwy. (After overpass, intersection)	2775				14	
Washington St. Opp. Franklin St. (Liquor Store)	2776				15	
Opp. #57 Washington @ Charles (Apartments)	2777				16	
Washington @ Cobble Hill Rd (Holiday Inn)	2778				17	
Cambridge Opp. Brighton St. (Opp. Donut Maker)	2779				18	
Cambridge @ Spice (Just after overpass)	2780				19	
New Sullivan Sq. Stn. (Orange Line T Station, Upper Level)	2874				20	
					21	
					22	
					23	
					24	
					25	
					26	

Route Name Sullivan Square to Central Square, Cambridge

Date _____ Begin End

Weather _____ Checker _____

Seating Capacity _____ Scheduled Time Actual Time

Cash _____

Tokens _____

Pennies _____

Day (Sunday=1) [1] | Route No. [2] 91.0 | Dir. [6] 1 | Leave Terminal [7] | Leave Terminal [11] | [15] -1 am -2 pm

STOP NAME	[15] NO.	[21] TIME	[25] ONS	[28] OFFS	[31]	
New Sullivan Sq. Stn. (Orange Line T Station, Lower Level)	28741				01	
Cambridge St. @ Maffa Way (Just past Celtic Tavern, front of parking lot)	2756				02	
Cambridge St. @ Brighton St.	2757				03	
Opp 116 Cambridge St. @ Parker St. (Gibbs gas station)	2758				04	
Washington St. @ Florence St. (Car wash)	2759				05	
Washington St. @ Franklin (Parise's Cafe)	2760				06	
Washington St. @ Tufts (Before overpass, no sign)	2761				07	
Washington St. @ McGrath Hwy. (Under McGrath Hwy.)	2762				08	
Washington St @ Boston (Girls & Boys Club)	2763				09	
227 Washington St @ Merriam	2510				10	
Washington St. @ Bonner Avenue	2612				11	
Webster Ave. @ Washington St. (No sign)	2511				12	
Webster Ave. @ Newton (These two	2512				13	
Newton @ Clark stops are very close together)	2765				14	
Newton @ Concord Ave. (Merger of 2 roads)	2766				15	
#62 Springfield @ Concord Ave. (No sign)	2767				16	
Hampshire St. @ Inman St. (Inman Sq) (Other side of intersection)	2439				17	
Prospect St. @ St Marys Road	2440				18	
175 Prospect @ Broadway (Before intersec)	2441				19	
Prospect St. @ Harvard (St. Marys) (No sign)	2442				20	
Prospect St. @ Bishop Allen Dr.	2443				21	
Western Ave. @ Green St.	2444				22	
					23	
					24	
					25	
					26	

ATTACHMENT D

QUESTIONNAIRE

(side 1)

№ 5374

Passenger Survey/Central North Corridor Bus Study

MASSACHUSETTS BAY TRANSPORTATION AUTHORITY

This survey is being done to help find out how bus service in this area should be improved. Please answer as many questions as you can.

When you complete the questionnaire, please hand it to the survey attendant on the bus or mail it. We will pay postage. Thank you.

1. Please fill in the route number and route name of the bus you are riding on.

   route number: [ ] (5) [ ] (7)

   route name: _____ [ ] (8)

2. Approximately what time did you get on this bus?

   [:] (9) -1 [ ] a.m. -2 [ ] p.m. (13)

3. How did you pay your fare when you got on this bus?

   [ ] (15)

   14-1 [ ] adult cash fare (or token)
   -2 [ ] adult monthly pass (circle one: A C D E F)
   -3 [ ] senior citizen fare
   -4 [ ] handicapped reduced fare
   -5 [ ] child/student cash fare
   -6 [ ] student pass
   -7 [ ] other_____

4. Please answer the following questions for your trip on this bus (even if this bus ride is only part of your entire trip).

   a. Where did you get on this bus?

   [ ] (16)

   _____
   (nearest street intersection or other landmark)

   b. How did you get to the bus stop?

   21-1 [ ] walked (from home, work, school, etc.)
   -2 [ ] transferred from another bus
   which route? 22 [ ] _____
   -3 [ ] transferred from Red, Green, or Orange Line
   -4 [ ] drove or rode and parked near bus stop
   -5 [ ] was dropped off
   -6 [ ] bicycle/moped
   -7 [ ] taxi
   -8 [ ] other_____

   c. Where will you get off this bus?

   [ ] (25)

   _____
   (nearest street intersection or other landmark)

BUSINESS REPLY MAIL

FIRST CLASS PERMIT NO. 2521 BOSTON MA

Postage will be paid by addressee

Central Transportation Planning Staff
Suite 2150
10 Park Plaza
Boston, MA 02116

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

d. What will you do when you leave this bus?

30-1 ☐ walk to my final destination
-2 ☐ transfer to another bus

which route? 31 ☐☐☐ _____

-3 ☐ transfer to the Red, Green, or Orange Line
-4 ☐ drive or ride in car parked near bus stop
-5 ☐ will be picked up by someone
-6 ☐ bicycle/moped
-7 ☐ taxi
-8 ☐ other_____

5. Please answer the following questions for the entire one-way trip you are now making (not just the bus portion).

a. Where did you begin this trip?

34-1 ☐ my workplace
-2 ☐ my home
-3 ☐ my school
-4 ☐ my shopping area
-5 ☐ other_____

b. Where is that located?

_____ 35 ☐☐☐
(city or town)

_____ ☐☐☐☐
(nearest street intersection or other landmark) 38

c. Where will this trip end?

43-1 ☐ my workplace
-2 ☐ my home
-3 ☐ my school
-4 ☐ my shopping area
-5 ☐ other_____

d. Where is that located?

_____ 44 ☐☐☐
(city or town)

_____ ☐☐☐☐
(nearest street intersection or other landmark) 47

6. How many days a week do you usually ride on the MBTA?

52-1 ☐ less than one
-2 ☐ 1-2 days
-3 ☐ 3-4 days
-4 ☐ 5 days
-5 ☐ more than 5 days

7. What is your age?

53-1 ☐ 17 or under
-2 ☐ 18-24
-3 ☐ 25-34
-4 ☐ 35-44
-5 ☐ 45-64
-6 ☐ 65 or older

8. Do you have a driver's license?

54-1 ☐ yes
-2 ☐ no

9. Did you have an automobile available for this trip?

55-1 ☐ yes
-2 ☐ no

10. What is your home zip code? _____ 56

What is your work (school) zip code? _____ 61

11. What is your annual family income?

66-1 ☐ under $5,000
-2 ☐ $5,000 - $9,999
-3 ☐ $10,000 - $14,999
-4 ☐ $15,000 - $19,999
-5 ☐ $20,000 - $29,999
-6 ☐ $30,000 - $39,999
-7 ☐ $40,000 - $49,999
-8 ☐ $50,000 or more

12. On the left, below, are listed several different measures of transit service quality. Please circle a number after each measure to indicate how you feel about service on THIS BUS ROUTE.

	very poor			average		unusually good	
Reliability (I can count on getting there on time)	1	2	3	4	5		67
Cleanliness of the buses	1	2	3	4	5		68
Comfort of the ride	1	2	3	4	5		69
Adequate seating on board	1	2	3	4	5		70
Appearance of the buses	1	2	3	4	5		71
Buses come on schedule	1	2	3	4	5		72
Courtesy of drivers	1	2	3	4	5		73
Helpfulness of MBTA personnel	1	2	3	4	5		74

Thank you for completing this survey. Please write any comments/suggestions in the space below. 75 ☐☐ 77 ☐☐ 79 ☐☐

(side 2)

APPENDIX B
ROUTE 70 ANALYSIS

CTPS

State Transportation Building
10 Park Plaza, Suite 2150
Boston, MA. 02116-3968
(617) 973-7100

CENTRAL TRANSPORTATION PLANNING STAFF

MEMORANDUM #2

TO: Central North Bus Study Files July 11, 1985

FROM: Karl H. Quackenbush

RE: Route 70 Analysis

Introduction

Recently, the MBTA Plans and Schedules department asked CTPS to analyze the potential impacts of two strategies for improving service on one of the MBTA local bus routes. Route 70, running between Central Square, Cambridge, and Cedarwood, Waltham, has, in recent months, been the subject of complaints regarding over-crowding and unreliability. Consequently, the Plans and Schedules department specified two alternative operating strategies for the route. The first strategy would involve operating fewer yet longer short-turns than now exist; the second would involve operating all long trips with no short-turns.

In the next two sections, more detail on present circumstances and proposed solutions is provided. Then the analysis results are presented. Following that is a section containing a summary and conclusions. Finally, Attachment A consists of a description of the analysis method.

Background and Task Description

The primary variation of Route 70, operated 9.9 miles between Cambridge and Waltham, is one of the longest local routes in the MBTA system. It traverses parts of Cambridge, Allston, Watertown and Waltham. High numbers of passenger-trip ends occur at Central Square, Arsenal Mall in Watertown, Watertown Square and Waltham Center. Transfer opportunities exist at all these points as well as in Allston.

The primary variation, referred to as 70.0, was the sole daytime, weekday variation operated on the route. Then, the Arsenal Mall opened in Watertown and in the Spring of 1984, in response to consequent complaints of overcrowding on the Central Square to Watertown Square segment of the route, the MBTA began operating peak-period short-turns between the two squares. The additional service provided by this new 70.2 variation reduced loads on the 4.2 mile segment to an acceptable level.

A Cooperative Transportation Planning Effort of the Executive Office of Transportation and Construction, Massachusetts Bay Transportation Authority MBTA Advisory Board, Massachusetts Department of Public Works, Massachusetts Port Authority, Metropolitan Area Planning Council

Currently, peak-period headways on the branch (west of Watertown Square where variation 70.0 operates alone) are 20 minutes. Peak-period trunk headways (east of Watertown Square) are irregular. Outbound, away from Central Square, they are designed to vary from five to 20 minutes as each short-turn precedes a long trip by typically five or sometimes 10 minutes. Conversely, inbound trunk headways are designed to be a regular 10 minutes, but in fact alternate between approximately seven and 13 minutes because inbound 70.0 buses take roughly three minutes longer than expected to reach Watertown Square where they then alternate with 70.2 buses.

In the non-peak directions of travel (AM outbound and PM inbound), the peak-load point is located in Allston, one to three stops east of North Harvard Street. The average peak-hour maximum load at this point is 45 in the morning and 39 in the afternoon, well within MBTA load standards.[1] However, in the peak directions of travel, the peak-load point is two to three stops west of Watertown Square, and it is from this area that the current complaints of overcrowding originate. The morning peak-hour, with an average maximum load of 69, is particularly crowded, due to the combination of school children and adult commuters. One trip was observed to have 85 passengers at the peak load point, possible only if most of them were not full-grown adults. The afternoon peak-hour is slightly less crowded with an average maximum load of 64 and a worst-case load of 80. In both the morning and afternoon, loads are sharply lower just east of Watertown Square and they taper rapidly west of the Square. Thus, maximum loads, although uncomfortably high, are of short duration.

One of the two problems with present Route 70 service, then, is the crowding that occurs west of Watertown Square. The other, more subtle problem is one of perceived unreliability. Overall schedule adherence is actually good and within MBTA standards.[2] CTPS observed 95% of all peak-period Route 70 trips leaving their terminals on time. Thus, many complaints about unreliability probably relate to the irregular trunk headways. Many passengers who do not consult the public timetables do not realize that much

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[1] A peak-hour standard is not explicitly defined. But the peak 30 minute standard is 140% of seated capacity and the total peak-period standard is 120%. By interpolating, and using an average seated capacity of 46, the peak-hour standard can be set at about 60 passengers. See Service Policy for Surface Public Transportation by the MBTA, August 1977.

[2] MBTA standards specify that 95% of a route's trips, when on 10-30 minute headways, will leave on time. On time is defined as 0-5 minutes late.

of the headway irregularity exists by design and they therefore view service as unreliable. Of course, headway irregularity, along with alternating short and long trips, can contribute to high variability in loads which, in turn, can lead to fluctuations in running times. But this "actual" unreliability is probably not as great as the "perceived" unreliability.

Alternative Operating Strategies

The first alternative is one which would physically extend the peak-period short-turns westward to Waltham Center, but reduce the number of both them and the long trips. Branch headways west of Waltham Center would be reduced to 30 minutes from the current 20 and headways on the new trunk would be an even 15 minutes instead of the present irregular, but average, 10 minutes on the present trunk. Vehicle requirements would drop to six from the current seven in the AM peak and to seven from the current eight in the PM peak.

In sum, the outer segment from Waltham Center to Cedarwood would receive less service, the middle segment from Waltham Center to Watertown Square, where the load problem occurs, would receive more service, and the inner segment from Watertown Square to Central Square would receive less but more regular service.

The second alternative would entail retaining the present number of vehicles, but reverting to the previous operation of long trips exclusively. This would result in even 15-minute peak-period headways. The inner segment would receive less and the middle segment more service than at present, just as in the previous alternative. However, the outer segment would receive more rather than less service.

Prior to implementing either strategy, the MBTA asked CTPS to derive answers to several questions. For the base case and each alternative, for each of the three route segments of interest, CTPS was to calculate:

- o average passenger wait time - peak periods
- o total passenger wait time - peak periods
- o average maximum loads - peak hours only
- o worst-case maximum loads - peak hours only, and
- o the number of passengers who would receive more versus the number who would receive less service.

Results

Tables One through Three summarize the results of the analysis. For the base case and the two alternatives, values are

TABLE 1 - PASSENGER WAIT TIME (MINUTES) - PEAK PERIODS

	Segment	Base Case Average	Base Case Total	Alternative 1 Average	Alternative 1 Total	Alternative 2 Average	Alternative 2 Total
AM OUTBOUND	Central Square - Watertown Square	8.7	7082	8.7	7110	8.2	5704
	Watertown Square - Waltham Center					8.2	938
	Waltham Center - Cedarwood	10.4	229	14.5	320	8.2	180
AM INBOUND	Central Square - Watertown Square	7.4	1972	7.5	1995	8.8	2328
	Watertown Square - Waltham Center	10.9	3689	7.5	2543	8.8	2966
	Waltham Center - Cedarwood	10.9	1447	15.0	1995	8.8	1164
PM OUTBOUND	Central Square - Watertown Square	8.7	9357	9.6	10312	7.7	6376
	Watertown Square - Waltham Center					7.7	1951
	Waltham Center - Cedarwood	9.5	143	14.1	211	7.7	116
PM INBOUND	Central Square - Watertown Square	7.6	3458	7.8	3553	8.2	3714
	Watertown Square - Waltham Center	9.4	2528	7.8	2097	8.2	2192
	Waltham Center - Cedarwood	9.4	1302	12.7	1755	8.2	1129
	TOTAL	8.8	31207	9.0	31891	8.1	28758

TABLE 2 - MAXIMUM LOADS-PEAK HOURS

	Segment	Base Case Average	Base Case Worst Case	Alternative 1 Average	Alternative 1 Worst Case	Alternative 2 Average	Alternative 2 Worst Case
AM OUTBOUND	Central Square - Watertown Square	45	59	56	59	56	56
	Watertown Square - Waltham Center	32		24	34	24	24
	Waltham Center - Cedarwood	16		24	24	12	12
AM INBOUND	Central Square - Watertown Square	31		39	49	39	39
	Watertown Square - Waltham Center	69	85	52	77	52	52
	Waltham Center - Cedarwood	36		54	54	27	27
PM OUTBOUND	Central Square - Watertown Square	45		57	62	57	57
	Watertown Square - Waltham Center	64	74	48	57	48	48
	Waltham Center - Cedarwood	11		17	17	8	8
PM INBOUND	Central Square - Watertown Square	39	80	58	61	59	59
	Watertown Square - Waltham Center	37		37	41	37	37
	Waltham Center - Cedarwood	13		17	17	13	13

TABLE 3 - NUMBER OF PASSENGERS RECEIVING MORE/(LESS) SERVICE COMPARED TO BASE CASE - PEAK PERIODS

	Segment	Base Case	Alternative 1	Alternative 2
AM OUTBOUND	Central Square - Watertown Square	-	(439)	(439)
	Watertown Square - Waltham Center	-	263	263
	Waltham Center - Cedarwood	-	(135)	(135)
AM INBOUND	Central Square - Watertown Square	-	(266)	(266)
	Watertown Square - Waltham Center	-	339	339
	Waltham Center - Cedarwood	-	(133)	133
PM OUTBOUND	Central Square - Watertown Square	-	(581)	(581)
	Watertown Square - Waltham Center	-	377	377
	Waltham Center - Cedarwood	-	(137)	137
PM INBOUND	Central Square - Watertown Square	-	(454)	(454)
	Watertown Square - Waltham Center	-	268	268
	Waltham Center - Cedarwood	-	(138)	(138)
	TOTAL	-	(1136)	50

reported for each peak period, by direction and by route segment. Due to technical constraints, wait times for the base case and Alternative one are presented as weighted averages for the segments comprising the trunks.[1] Worst-case maximum loads in the base case were only calculated for the segments containing the route's maximum load point: those for the other segments are not relevant to the analysis.[2]

Alternative two, in which long trips would be operated exclusively, would result in a decrease in average and total passenger wait time for the route as a whole. Average maximum loads in six period-by-direction-by-segment cases would decrease, would remain stable in two and increase in four (See Table One). Most important, because all trips would be of even length and spacing, worst-case maximum loads on the most congested segments would decrease yet those on other segments would not violate standards. Finally, passengers whose level-of-service would increase, marginally outnumber those whose service would decrease.

Alternative one, in which short-turns would be lengthened, would result in essentially unchanged values of average and total wait time for the route as a whole. Average maximum loads would decrease in only three period-by-direction-by-segment cases, remain stable in one, and increase in eight. As in Alternative two, but to a lesser degree, the most worrisome of the worst-case maximum loads would be "flattened" or decreased to within standards yet no others would increase to the point of violating the standard. Worst-case maximum loads would exceed those of Alternative two, because, with alternating long and short trips, loads on the trunk would be more variable. As opposed to Alternative two, passengers whose level-of-service would decrease outnumber those whose level-of-service would increase.

Viewed on a route segment-by-segment basis, either alternative would provide more service to the middle segment, which is the most crowded of the three and the one which spurred thinking about alternatives. The inner segment would receive slightly less service under either alternative, but loads there would remain within standard. Also, service there would be on even headways, whereas at present it is not. The outer segment, which experiences the least ridership, would receive more service under Alternative two and a lesser but within standard level of service under Alternative one.

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[1]This was done to avoid having to make assumptions concerning the origin or destination segments of passengers on individual trunk segments.

[2]Note that the route has an overall maximum load point which is the greatest of the maximum load points on each of the segments.

Summary and Conclusions

CTPS was asked to evaluate the relative merits of two alternative operating strategies for MBTA bus route 70. Impetus for the evaluation was provided by complaints of unreliability generally and overcrowding specifically on the Waltham Center to Watertown Square segment of the route. Using existing ridecheck data, for each of the two alternatives, the following were calculated and compared to the base case: average and total passenger wait times, average and worst-case maximum loads, and the numbers of passengers benefitted and inconvenienced.

Either alternative would provide relief to crowding on the Waltham Center to Watertown Square route segment without providing a substandard level of service elsewhere. Likewise, either would provide a greater degree of actual and perceived reliability. Actual reliability would improve due to somewhat more stable loads, hence more even running times, and perceived reliability would improve due to this and to even design headways.

The appeal of Alternative two over Alternative one lies in its provision of a relatively greater degree of relief to the most crowded trips, its decreased overall wait times and essentially unchanged net impact on the number of passengers benefitted versus inconvenienced.

Alternative one theoretically inconveniences more passengers than it benefits, in terms of the number of trips provided, and does not achieve an overall savings in wait time. However, its appeal lies in the fact that it can flatten worst-case loads to within standards, maintain within-standard loads and headways elsewhere, and provide even trunk headways while at the same time saving a vehicle in each peak-period. Furthermore, most of the passengers theoretically inconvenienced - those on the inner of the three segments - would not be, as a practical matter. The increase in their average wait time would be measured in unnoticeable fractions of a minute, and might be more than compensated for by having even headways. In contrast, benefits to passengers on the middle segment of the route would be noticeable. The average passenger on that segment would save from one-half to one minute more than in Alternative two and from two to three minutes more than in the base case.

Finally, the argument in favor of the base case is its stability. People have based their travel behavior on the existing schedule, and a change in a departure time, even as minor as five minutes, would undoubtably be viewed as an inconvenience by some. The amount of overall inconvenience created might more than offset the targetted benefits of a service change. Moreover, if an alternative, once implemented, resulted in even more complaints than now exist, and a change back to the base case or to something else were implemented, more instability would be introduced.

ATTACHMENT A

Analysis Method

Preliminary

The data for the analysis were derived from the November 1984 ridechecks done by CTPS for the Central North Bus Study. Boardings and alightings by stop and trip times by route segment obtained by the ridechecks were used to develop peak-period and peak-hour load profiles and trip-time tables for the three analysis segments of Route 70.

One time-saving assumption underlying the analysis is that ridership would not change in response to either of the alternatives. Since most passengers would experience only small changes in their levels-of-service, and since survey data collected in February 1985 reveal a high degree of transit dependency on the route, it is reasonable to assume stable ridership.

Analysis periods for each peak-period coincide roughly with the periods in which variation 70.0 is currently operated on 20-minute headways. Thus, in the morning, all outbound service between 5:47 and 8:35 AM and all inbound service between 6:25 and 8:45 AM is included. In the afternoon, outbound service between 3:10 and 6:35 PM and inbound service between 3:05 and 6:25 PM is included.

Wait Times

There are two methods for calculating average passenger wait time - empirically and theoretically. The latter method was used in order to enable comparisons between the base case and the hypothetical operating strategies.[1] The following formula was used.

$$\bar{W} = \frac{\sum_{i=1}^{N} \left(\frac{H}{2} H\right)}{\sum_{i=1}^{N} H}$$

where:

$\bar{W}$ = average passenger wait time/period/direction/segment
H = headway
N = number of bus trips/period/direction/segment

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[1] As a check, empirical wait times for the base case were calculated. In most cases, they were within fractions of a minute of the theoretical wait times.

This method assumes that the average passenger wait time for a given bus is one-half the headway. This value is then weighted by the headway because it is assumed that the number of passengers boarding a bus at a given stop is directly correlated with the headway preceding the bus. The resulting values are then summed for all buses and divided by the sum of the headways to derive an average for the period, direction and segment.

In reality, there is a maximum headway over which passengers time their bus stop arrivals to avoid excessive waiting at the stop. But in the present analysis, wait time also includes "inconvenience" time spent at home or elsewhere while waiting to leave for the bus stop. The assumption is that the larger the headway, the less flexibility people have in leaving for the stop whenever they want to hence the more they are inconvenienced. It is arguable whether this inconvenience penalty exists in the long-term as people adjust to a particular schedule or whether the penalty is inherent in longer headways, but it is used here to avoid the appearance that long headways are as convenient as short ones (which can happen when a ceiling on wait time is imposed), and since all three scenarios were treated alike, no distortion in the relative values among scenarios was introduced.

For Alternatives one and two, hypothetical schedules were established within the analysis periods based on the number of vehicles to be used and the cycle time for each route variation. For the trunk portion of the base case and the extended trunk portion of Alternative one, average wait time was calculated first for combined headways and then for long trip headways alone. Average wait time was then derived for each of these segments as a whole by weighting the two average wait times by the number of passengers affected by each.

Total wait times for all segments in all scenarios were calculated by simply factoring the average wait time encountered on each by the appropriate number of passengers. Total wait time per direction for the route was then the sum of the wait times on each segment.

The 70.2 variation actually terminates at Watertown Yard, south of Watertown Square. It was assumed that people who board at the Yard do so regularly and are indifferent to the combined 70.0/70.2 level-of-service they would encounter by walking over the bridge to the Square. Thus, wait times for this small spur were calculated separately in the base case scenario.

Maximum Loads

The current peak-hour and route maximum load point for each peak-period and direction were identified. Load profiles for the few trips comprising each peak hour were developed so that passenger flow from one part of the route to another could be determined. Some assumptions regarding the trip-ends of passen-

gers at segment maximum load points were necessary, but the analysis results are not sensitive to varying these assumptions. The peak-hour in the morning was determined to be 7:27 - 8:26 AM inbound and 7:07 -8:06 outbound. In the afternoon, it is 4:14 - 5:13 PM inbound and 5:09 - 6:08 PM outbound.

For the base case, the average maximum load and the worst-case maximum load for the route for each peak hour and direction were determined empirically. For Alternative two, average maximum loads for each segment were calculated simply as the total maximum load divided by the new number of peak-hour vehicle-trips. Because all trips in this alternative would be evenly spaced and of the same length, loads would be fairly even, so it was assumed that the worst-case maximum load would be equal to the average maximum load.[1]

For Alternative one, maximum load calculations were complicated due to alternating trips of different length. On the branch, calculations were done as for Alternative two above. On each of the two trunk segments, average maximum load was again simply a function of total maximum load and the new number of vehicle trips. Worst-case maximum loads for each segment, however, were found by first calculating them for the long trips and short trips separately, using the following formulas:

$$\text{Worst-Case Maximum Load - Short Trips} = \frac{X}{W}$$

$$\text{Worst-Case Maximum Load - Long Trips} = \frac{X}{W} + \frac{Y}{Z}$$

where:

X = The number of passengers at the maximum load point who travel between there and a point further west on the trunk.

Y = The number of passengers at the maximum load point who travel between there and the new branch.

W = The new number of trunk vehicle-trips.

Z = The new number of branch vehicle-trips.

In effect, the long trips would experience the "worst" worst-case maximum loads, at least in the short-term, as it was assumed that

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[1]Note the distintion between the route's maximum load and maximum load on each segment. The former is the greatest of the latter set.

trunk travelers would distribute themselves evenly and be added to, in the case of these long trips, branch travelers. So, the worst-case maximum load for the segment is equal to that of the long trips (See Table Two).

Passengers Inconvenienced Versus Benefitted

The number of passengers by segment, peak-period, and direction, who would experience an increased or decreased level-of-service under Alternatives one and two, was equal to the number of inbound boardings or outbound alightings on each segment by period. A decreased level-of-service was defined as fewer vehicle trips. The figures reported in Table Three are net.

APPENDIX C
BUNCHING OF BUSES ON BROOKLINE AVENUE

CTPS

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CENTRAL TRANSPORTATION PLANNING STAFF

MEMORANDUM

TO: Central North Bus Study Files September 19, 1986

FROM: Karl H. Quackenbush

RE: Bunching of Buses on Brookline Avenue

I. Introduction

There has been some concern expressed to the MBTA by community officials regarding the tendency of MBTA buses on Brookline Avenue to bunch up and thereby cause irregular and long headways. This memorandum presents the results of an examination of this problem, hereinafter referred to as platooning. The memorandum begins with a discussion of the nature of platooning, followed by descriptions of existing MBTA bus service on Brookline Avenue and existing conditions there. Alternative measures for mitigating platooning are then briefly discussed and a suggested strategy is presented.

The suggested strategy entails eliminating some peak period service on one of the routes involved, an admittedly non-standard solution to bus platooning. Examination of the productivity and boarding/alighting pattern of Route variation 60.1 led to the conclusion that it could be eliminated with little harm to passengers, thus serving the objective of releasing unproductive capacity for use elsewhere in the system, while at the same time reducing the incidence of platooning on Brookline Avenue.

II. Platooning

The fact that buses on Brookline Avenue have a tendency to platoon is the result of three factors common to many urban bus routes: short headdways, running time variability, and passenger demand. Buses operating on small headways will have a greater tendency to platoon, all else being equal, than those operating on large headways, due to the smaller gaps separating buses at the beginning of one-way trips. Secondly, large variations in running time over a segment will affect platooning, all else being equal, due to the delays that may affect one bus, but not its follower, which then catches up to its leader. Inherent in highly variable running times are the effects of traffic congestion and traffic signals. A third and closely related factor affecting platooning is passenger demand. As a bus falls behind schedule, a greater gap in service precedes it, during which time more passengers accumulate at stops. More passengers

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mean additional dwell time and consequently, the bus falls further and further behind schedule, while its follower, encountering fewer waiting passengers, catches up.

Platooning is undesirable for various reasons. First and foremost, it contributes to unreliability. To the extent that passengers time their arrivals at stops, irregular headways, implied by platooning, will increase their wait time and decrease their ability to correctly time their arrival at their destination, resulting sometimes in missed transit connections. In addition to real unreliability, the sight of buses traveling in bunches fosters among riders and non riders alike the perception of unreliable or poorly scheduled service.

The uneven loads among buses that platooning can cause can also be a detriment to passengers. At the least, when loads are not too high, uneven loads can increase the likelihood of passengers having to stand on some of the fuller buses. Moreover, if loads are generally high in a given period, unevenness can increase the likelihood of some buses reaching total capacity and therefore passing waiting passengers.

Finally, bus platoons can impact automobile and bus traffic adversely. Automobile drivers on the same alignment may find it difficult to negotiate in and around a bus platoon and cross-traffic may be blocked by a trailing bus caught in an intersection after a signal change. Buses arriving at terminals in platoons may strain the layover capacity of a terminal and slow operations there.

III. Existing Bus Service

Three MBTA bus routes operate over all or part of Brookline Avenue: 47, 60 and 65. Route 47 only operates over a 0.35 mile segment between Longwood Avenue and Park Drive. It was not cited as being a part of the platooning problem and will, therefore, be excluded from the analysis. Routes 60 and 65 operate over the entire length of Brookline Avenue from Brookline Village to Kenmore Square, a distance of 1.6 miles. These are the routes that platooning problems have been observed on.

Route 60 has three major variations. Variation 60.4, run during peak periods, begins at Chestnut Hill and operates over Route 9 into Brookline Village and then into Kenmore Station along Brookline Avenue. Variation 60.0, run during the off-peak, is identical to 60.0 except that it deviates off Route 9 onto Cypress and High Streets in Brookline. Variation 60.1, a short-turn run during peak periods along with 60.4, starts at Cypress and High Streets and runs in through Brookline Village to Kenmore Station.

Route 65 has only one routing and operates all-day from Brighton Center, along Washington Street to Brookline Village, then into Kenmore Square.

During the midday, 60.0 and 65.0 each operate on 30 minute headways, with a combined trunk headway of 15 minutes. In the peaks, 60.1 and 60.4 operate on a combined alternating trunk headway of 17 and eight minutes. Route 65 operates on 20 minute headways in the morning peak and 25 in the afternoon peak. In the morning, then, trunk service on Brookline Avenue operates on irregular headways ranging from one to 11 minutes, and in the afternoon, on alternating eight and nine minute headways.

IV. Conditions on Brookline Avenue

Brookline Avenue is heavily congested with traffic. Several major hospitals located there generate high volumes of traffic and a few signalized intersections cause major backups. Buses, which experience many boardings and alightings there, are often prevented by on-street parkers from pulling over to the curb to stop. Buses, then, are affected by, and contribute to, congestion.

The incidence of platooning is more noticeable in peak periods and attention will consequently be focused there. In the midday, only four buses per hour traverse Brookline Avenue. However, during the peaks up to nine buses per hour in the AM and eight in the PM do so.

During ridechecking, different vehicle trips were observed on different days, so no direct documentation of platooning exists. However, field observations made during the course of ridechecking do confirm the existence of platooning and average trip times for a "composite day" were used in analyzing the problem.

Table 1 contains "composite day" running time statistics for both routes in the AM peak, inbound direction. It is in the inbound direction that the greater potential for platooning occurs due to the three separate routes/variations converging on the trunk after they have traversed their respective branches: there is less control over their times of arrival onto the trunk, hence their spacing, than in the outbound direction, when buses are dispatched from Kenmore Station immediately onto the trunk.

The table shows when buses are scheduled to arrive at Brookline Village (the beginning of the trunk) and Kenmore Station (the end), compared to when they actually arrive at these points, on average. The figures in the table help to illustrate three points.

First, the potential for platooning becomes clear by comparing the actual average trunk headways to the standard deviations of actual mean arrival times, both at Brookline Village and Kenmore station. The larger the standard deviation is relative to the headway, the greater the potential for buses to be spaced closely or to platoon. On this basis, one can see

TABLE 1
AM INBOUND RUNNING TIME STATISTICS

Route	Leave End of Line	*BROOKLINE VILLAGE* Scheduled Arrival	Trunk Scheduled Headways	Mean Actual Arrival	St. Dev. of Mean Actual Arrival	Trunk Actual Headway	*KENMORE STATION* Scheduled Arrival	Trunk Scheduled Headways	Mean Actual Arrival	St. Dev. of Mean Actual Arrival	Trunk Actual Headway
65	710	723		727	4.1		734		745	5.7	
60.4	720	734	11	733	2.3	6	745	11	752	5.9	7
60.1	735	742	8	740	1.4	7	753	8	758	7.5	6
65	730	743	1	747	4.1	7	754	1	805	5.7	7
60.4	740	754	11	753	2.3	6	805	11	812	5.9	7
60.1	757	804	1	802	1.4	9	815	1	820	7.5	8
65	750	803	9	807	4.1	5	814	9	823	5.7	3
60.4	800	814	10	813	2.3	6	825	10	832	5.9	9
60.1	820	827	4	825	1.4	12	838	4	843	7.5	11
65	810	823	9	827	4.1	2	834	9	845	5.7	2
60.4	820	834	7	833	2.3	6	845	7	852	5.9	7
60.1	842	849	6	847	1.4	14	900	6	905	7.5	13
65	830	843	9	847	4.1	0	854	9	905	5.7	0
60.4	840	854	5	853	2.3	6	905	5	912	5.9	7
Mean Headway Preceding:											
60.1			4.8			10.5		4.8			9.5
60.4			8.8			6		8.8			7.4
65			7			3.5		7			3

that there is great potential for buses to platoon on Brookline Avenue, particularly as the buses near Kenmore Station.

Secondly, buses are scheduled to enter the trunk at irregular intervals and, indeed, do so, although not with the same intervals that the MBTA intends. As shown in the table, buses actually enter the trunk at Brookline Village, on average, as follows: 60.1 followed 3.5 minutes later by 65; 65 followed 6 minutes later by 60.4; 60.4 followed 10.5 minutes later by 60.1; and so on. By the time buses arrive at Kenmore Station, the average trunk headways are still close to what they are at Brookline Village, even though their variability has increased. Thus, the potential for platooning is enhanced due to the irregular headways with which buses enter the trunk, and these same irregular intervals are not evened, but retained, on average, over the course of trunk travel.

One factor that contributes, no doubt, to the irregular intervals with which buses enter the trunk is the very tight schedules they operate on. All are operating with almost no slack, so there is little leeway in when inbound buses depart their terminals. This, in combination with the fact that variation 60.1 is on a 45-minute cycle time as opposed to the 60-minute cycle times of variation 60.4 and route 65, dictates that variation 60.1 buses are necessarily going to mesh with their leaders at increasingly larger intervals through the period. Indeed, the interval between variation 60.1 buses and preceding variation 60.4 buses entering the trunk goes from seven, through nine and 12, to 14 minutes through the period. Consequently, the interval between variation 60.1 and following route 65 buses decreases over time - from seven minutes at the beginning to 0 minutes at the end of the period.

The final point illustrated by Table 1 is, quite simply, that actual running times exceed scheduled running times on all three routes/variations. This, in itself, does not directly cause platooning. As alluded to, it causes irregular headways to exist in a different pattern from that scheduled, (the smallest headway is intended to exist between variation 60.4 and following variation 60.1 buses, rather than between route 65 and preceding variation 60.1 buses, as it does). More important, the longer than expected running times diminish recovery times and under these circumstances, it is more difficult for buses to maintain whatever schedule they are on, present or otherwise, and platooning, when it exists, will be harder to schedule against.

In the AM peak, outbound direction, (not shown in Table 1), actual and scheduled running times are quite close, as are scheduled headways out of Kenmore and actual mean headways at Brookline Village. In other words, much less variability in running times exists in the outbound direction. The platooning problem in the AM peak is primarily an inbound phenomenon.

Table 2 contains running time statistics for the PM peak, inbound direction. Again, service is scheduled to be irregular on the trunk, and it is in fact, and this can enhance the potential for platooning. However, the variability of arrival times at Brookline Village and Kenmore Station, relative to headways, is much less than it is in the AM peak. Also, scheduled and actual running times are quite close to one another and cycle times (not shown) are liberal. Platooning in the PM peak, inbound direction would, then, appear to be more preventable through scheduling changes than in the AM peak period and less likely to occur in the first place.

In the PM peak, outbound direction, buses depart Kenmore Station on fairly uniform headways. Variation 60.1 buses follow Route 65 buses by nine minutes and are followed by variation 60.4 buses eight minutes later. The latter are in turn followed by Route 65 buses eight minutes later. However, by the time buses arrive at Brookline Village, the gap between Route 60 and succeeding Route 65 buses is three minutes greater than that between Route 65 and succeeding Route 60 buses. Boarding patterns reveal that Route 65 buses are slowed relative to those on Route 60, in part, due to higher demand. An average of 32 passengers per bus board Route 65 on the trunk, after Kenmore Station, whereas the comparable figures for 60.1 and 60.4 are 15 and 22 respectively.

V. Alternative Strategies for Lessening Platooning

Several options for mitigating platooning were examined and discarded. Many involved decreasing the level of bus service on Brookline Avenue. Simply reducing the frequency of buses seemed inappropriate given the demand that exists. Rerouting some or all Route 60 or 65 bus trips away from Brookline Avenue is not feasible given the high number of passenger trip-ends there and the lack of a suitable alternate routing. Operating Route 60 peak period service between Chestnut Hill and Brookline Village only, as is done in a few off-peak instances, was considered, but given the high number of forced transfers to Route 65 or the Green Line that would result, it was rejected.

Most strategies for mitigating platooning revolve around bus priority schemes or mid-route holding or expressing strategies, rather than in reducing levels of service. These strategies must be well tailored in order that resulting benefits, in terms of transit passenger and auto passenger travel times, outweigh disbenefits. An analysis of these strategies is beyond the scope of this memorandum and therefore no specific such strategy is suggested. However, it is suggested that some sort of holding/expressing strategy be analyzed or operated experimentally if the following suggested strategy fails to reduce platooning acceptably.

VI. Suggested Strategy

During the course of this analysis, the low productivity of the peak period short-turn, 60.1, became evident. It is one of

TABLE 2

PM INBOUND RUNNING TIME STATISTICS

Route	Leave End of Line	*BROOKLINE VILLAGE* Scheduled Arrival	Trunk Scheduled Headways	Mean Actual Arrival	St. Dev. of Mean Actual Arrival	Trunk Actual Headway	*KENMORE STATION* Scheduled Arrival	Trunk Scheduled Headways	Mean Actual Arrival	St. Dev. of Mean Actual Arrival	Trunk Actual Headway
65	408	422		422	3.3		435		434	5	
60.1	425	430	8	428	1.4	6	443	8	441	2.6	7
60.4	417	432	2	430	1.6	2	445	2	442	2.6	1
65	425	439	7	439	3.3	9	452	7	451	5	9
60.1	450	455	16	453	1.4	14	508	16	506	2.6	15
60.4	442	457	2	455	1.6	2	510	2	507	2.6	1
65	450	504	7	504	3.3	9	517	7	516	5	9
60.1	515	520	16	518	1.4	14	533	16	531	2.6	15
60.4	507	522	2	520	1.6	2	535	2	532	2.6	1
65	515	529	7	529	3.3	9	542	7	541	5	9
60.1	540	545	16	543	1.4	14	558	16	556	2.6	15
60.4	532	547	2	545	1.6	2	600	2	557	2.6	1
65	540	554	7	554	3.3	9	607	7	606	5	9
60.4	557	612	18	610	1.4	16	625	18	622	2.6	16
Mean Headway Preceding:											
60.1			16			14		16			15
60.4			2			2		2			1
65			7			9		7			9

the least productive single variations in the Central North bus study area. It carries only 43.4 passengers per hour as opposed to an average in the study area of 71.7. Furthermore, an examination of boarding and alighting patterns revealed that the number of passengers whose trips could not be served just as well by the longer variations was quite small. Finally, it was seen that loads on the trunk, if 60.1 were non-existent, would be higher, but not uncomfortably so.

Due to these findings, it is suggested that 60.1 be considered for elimination both because of its low productivity and as a simple way of reducing bus presence, hence the potential for platooning, on Brookline Avenue. With no offsetting increase in the number of long trips on Route 60, buses per hour on Brookline Avenue would decrease from 9 to 6 in the AM peak and from 8 to 6 in the PM peak.

If 60.1 service were eliminated, two accompanying actions should be considered. Remaining peak period service should be routed as 60.0 along Cypress and High streets, as it is in the off-peak, thus minimizing the adverse effect of eliminating 60.1 service from the neighborhood. This routing would add only three minutes to the travel times of peak-period passengers who have a trip-end west of Cypress and Boylston Streets. Departure times should be coordinated with those of Route 65 to ensure even trunk headways of 10 minutes in the AM peak and 12.5 minutes in the PM peak period.

If service on variation 60.1 were retained, then slight schedule changes might help alleviate the potential for platooning. In the AM peak, where the greatest potential for problems exists, inbound route 65 buses might be scheduled one or two minutes later in order to even out some of the irregularity with which buses enter the trunk. It is not recommended that, instead, 60.1 buses be dispatched one or two minutes earlier, because its tight schedule would dictate that outbound trips then leave even closer behind 60.4 trips than they do now (the gap is two minutes now). Admittedly, the same tight schedule considerations would dictate that, if 65 inbound trips were delayed, so too would outbound trips, but an average of nine minutes currently separates Route 65 and following variation 60.4 trips, so no problem would be introduced outbound by attempting to mitigate an inbound problem.

In the PM peak period, inbound direction, variation 60.1 buses could be dispatched a few minutes earlier to lessen the smallest average intervals, and due to the slack that exists in its schedule in the period, it could still be dispatched outbound as it is now, thus retaining the even outbound spacing. The effect of this wold be to shift more of the variation's recovery time from the outer to the inner terminal. Furthermore, due to outbound Route 65 buses experiencing more delays along the trunk than the others, they could be dispatched one or two minutes

earlier in order to create even outbound intervals over a longer portion of the trunk.

The potential for buses to platoon on Brookline Avenue is great enough that minor schedule changes might not help significantly. Whether or not variation 60.1 service is retained, the benefits of a mid-route holding or expressing strategy should be analyzed. Such intervention in service is the most logical and direct vary of minimizing platooning, because it breaks up platoons as they occur.

VII. Impacts of Eliminating 60.1

A handful of people would lose their current, direct service if variation 60.1 were eliminated and 60.0 operated in peak periods. In the morning peak, five individuals, representing nine percent of the 60.1 boardings in the period, would be unable to travel from Cypress Street to the segment of Route 9 between Cypress and High Streets. Since there is a school near Route 9 on that segment, these are probably school children. In the PM peak, outbound direction, two people who currently alight on the Route 9 segment between Cypress and High Streets would lose direct service. No one currently riding 60.1 in the non-peak directions would lose service. An average of six individuals or two percent of 60.4 peak riders who currently board or alight 60.4 buses on Route 9 between Cypress and High Streets would also lose direct service if 60.4 were replaced by 60.0 service in peak periods.

Notwithstanding these losses, 60.0 is preferable to 60.4 because the Cypress Street area accounts for 30 to 40 individuals or 40-46 percent of the peak-direction passengers currently riding 60.1. Furthermore, some modest ridership gains could be expected to occur on High Street, which currently lacks peak period service.

Current 60.4 riders who have one trip-end west of Cypress and Route 9 and one east of High and Route 9 will be inconvenienced by having to ride through the deviation that 60.0 entails: an average of three minutes would be added to the trip times of 107 individuals or 59 percent of those who ride the variation.

The final impact of eliminating 60.1 would be on the loads of remaining buses. Maximum loads on them would increase, but few or no standing loads would occur. Maximum loads on 60.0 buses in the AM peak inbound direction, the most crowded period and direction of the day, would go from an average of 28 to just about seated capacity at 42. The worst-case maximum load would probably occur on what is now the 60.4, 7:40 AM inbound trip. Its current load just past Brookline Village is 42. Its load there could increase to a standing load, but given that Route 65 buses currently pass this point with excess seated capacity, no

uncomfortably high load would occur on that trip or on any of the 65 buses, which have passed through their maximum load points prior to entering the trunk.

KHQ:sfw:22305

APPENDIX D
ROUTE 47 UNRELIABILITY

CTPS

State Transportation Building
10 Park Plaza, Suite 2150
Boston, MA 02116-3968
(617) 973-7100

CENTRAL TRANSPORTATION PLANNING STAFF

MEMORANDUM

TO: Central North Bus Study Files September 19, 1986

FROM: Karl H. Quackenbush

RE: Route 47 Unreliability

Route 47 is considered by many riders, community officials and MBTA officials to be among the least reliable routes in the MBTA system. CTPS was asked to analyze the route to see whether its reliability can be improved, and this memorandum documents the results of such an analysis.

The basic findings of the analysis are that Route 47, indeed, has a measurable reliability problem, that much of its problem, being a result of its operating environment, is not readily surmountable, but that some improvement can be wrought. Specifically, changes to the route's schedule and improved public information could perceptably improve reliability.

In the following section, Route 47 is briefly described. The issue of bus service unreliability is then discussed followed by an accounting of the conditions that contribute to Route 47's unreliability. Concrete evidence of the route's problems is then presented and finally, some options for improving reliability are suggested.

II. Description of Route 47

The route is classified as a cross-town route, running as it does from Central Square, Cambridge to Boston City Hospital. It traverses Brookline and Pearl Streets in Cambridge; Park Drive, Brookline, Longwood and Huntington Avenues in the Fenway area; and Ruggles and Washington Streets and Harrison Avenue in Roxbury and the South End.

Major travel generators served by the route include Central Square, Boston University, the hospital area in the Fenway, Dudley Square and Boston City Hospital. The route connects to the Red Line in Central Square, all four branches of the Green Line, and the Orange Line at Dudley Square.

A Cooperative Transportation Planning Effort of the Executive Office of Transportation and Construction, Massachusetts Bay Transportation Authority, MBTA Advisory Board, Massachusetts Department of Public Works, Massachusetts Port Authority, Metropolitan Area Planning Council

The basic variation - 47.0 - operates all day on 18 and 20-minute headways and at night on 30-minute headways. Morning and afternoon peak-period service is supplemented by variation 47.4, which operates over the same alignment but between Boston City Hospital and Brookline Avenue/Park Drive only. Combined scheduled headways on this trunk segment are five and 10 minutes in the morning and six and 12 minutes in the afternoon.

III. Unreliability of Bus Service

Unreliability can refer to various specific attributes of service or to a general feeling that a route does not serve ones travel needs well. Specific instances of unreliability include buses appearing late, at irregular intervals or not at all; buses breaking down with passengers on-board; and buses being so crowded that one cannot board. Unreliability may even be based on a perception with no basis in fact. For instance, one might view bus sevice operating with an irregular frequency as unreliable, even though it may be scheduled to do so.

There are, then, many dimensions to the issue of unreliability, and the analysis described herein does not address all of them. No analysis of missed trips or miles-per-road-call was conducted, for instance. However, some commonly used indicators of unreliability were analyzed and from this, a good profile of the route's problems was developed.

IV. Contributors to Route 47's Unreliability

Based on its operating environment, one might expect Route 47 to be among the MBTA routes experiencing reliability problems. The route traverses an alignment that is heavily congested with traffic. Many of the streets are narrow with one lane in each direction and signalized intersections abound. It is a long route - at over 10 miles, one of the longest in the study area - and somewhat circuitous. In short, the environment in which the route operates works against reliable transit service, and due to its length, problems, once they appear, can propogate.

Patronage characteristics also contribute to an unreliable environment. The route is heavily patronized: its 84 boardings per hour make it the second most productive route in the corridor. Heavy patronage implies more dwell time, both because of the high number of stops made and because crowded buses slow boarding and alighting. High dwell times, while not necessarily contributors to unreliability may contribute to an environment in which buses, once off schedule, may become more so. Moreover, the pattern of demand, which is neither even along the route, nor consistent among time periods, can contribute to erratic running times within and between periods. Shift change time in the hospital area, for instance, is associated with a sudden surge in demand in the middle of the route and may affect one bus-trip much more than the next.

A final contributor to at least the perception of unreliability of Route 47, is that many people using it do not have firm control over their arrival time at their bus stops. Roughly 30% of the route's users arrive at a Route 47 bus stop after alighting from another bus or from rail transit. To the extent that travel times on these other lines are variable, the passengers' bus stop arrival times will be variable, and when Route 47 buses are running off schedule (or even if they are not), impressions of unreliability may be fostered.

V. Evidence of Unreliability

Four sources of information provide evidence of Route 47's unreliability. Late terminal departures, running time variability and scheduled headways are documented and can be analyzed objectively. Also, passenger perceptions, gleaned from a survey, provide some additional subjective insight, as do field observations of the routes operation.

On the basis of late terminal departures, Route 47 is the worst performer in the Central North Corridor. Lateness is evident in practically all time periods on both major variations. Table 1 depicts the time periods in which service is unacceptably late according to MBTA service policy. Variation 47.4 A.M. peak period service, although not unacceptably late, is not entirely free of lateness either.

Table 1
Unacceptably Late Service
According to MBTA Service Policy

Variation	Period	Direction	#Observed Trips	#Trips > 5 Mins. late	%Trips "On Time"
47.0	A.M. Peak	out	7	1	85
	Midday	out	17	4	76
	School	out	9	1	89
	P.M. Peak	in	7	2	71
	Evening	out	4	1	75
	Night	out	9	1	89
47.4	School	out	5	1	80
	P.M. Peak	out	9	3	67
	P.M. Peak	in	7	3	57

Much of the Route's lateness can be linked to its schedule characteristics. That is, there are times during the day when scheduled cycle time is not much greater than mean round-trip running time. Clearly, the smaller the cycle-to-running time ratio, the greater the chance of buses falling behind schedule.

The basic schedule problem is that observed round-trip running times exceed scheduled running times at all times of the

day, as shown in Table 2. The difference is as little as two minutes and as great as 14, but in all cases, it causes recovery time to be less than expected. As the table shows, the scheduled cycle-to-scheduled-running-time ratios appear reasonable, but the actual ratios, based on observed running times, are, in several cases, dangerously low.

Running time variability provides more evidence of the route's reliability problems. Depicted in Table 2 are the standard deviations of the mean round-trip observed running times and the standard deviations divided by the means. The route does not rank among the very worst in terms of erratic runing times, but there are some periods such as the P.M. peak, in which running times are alarmingly variable on one variation and this may cause some real, or at least perceived, unreliability.

Of greater significance is the interaction of the scheduled cycle times, observed running times and the standard deviations of the running times. In some cases, these things in combination practically guarantee that trips will be late. For instance, given the values in the table for these three variables, statistical probability dictates that the second round-trip in a driver run on 47.4 P.M. peak period service will have about a 40% chance of being late.[1]

Not only do highly variable running times affect the chances of succeeding trips in a run being late, but they, in combination with headways, indicate the potential for buses to bunch up or platoon. Bus platoons are perceived by passengers to be an inherent indication of unreliability, and when they contribute to uneven loads on successive buses, they increase the chances of passengers having to stand or being unable to board some vehicles if crowding is severe.

The following values, pertaining to P.M. peak outbound ser vice, provide an example of the platooning potential.

VARIATION	#TRIPS	MEAN TRUNK RUNNING TIME	STD DEVIATION	PRECEDING HEADWAY
47.0	7	24.9	5.6	12
47.4	6	26.8	5.5	6

The range of running times around the mean, as demarcated by the standard deviation will include roughly 68% of the trips and about 16% of the trips will fall to one side of this range. If a

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[1]Assumes normal population and andom sample. Late = cycle time + 1 minute = 55. $Z = (55 - \bar{X})/ST. DEV. = .2062$. Area under Curve = .0832 Therefore, area outside = .4168.

TABLE 2
Route 47 Time-Related Characterestics

47.0

PERIOD	# (%) TRIPS> 1 MIN. LATE	SCHEDULED CYCLE TIME	ROUND TRIP RUNNING TIME				CYCLE/RUN TIME	
			SCHEDULED	OBSERVED	ST. DEV.	ST. DEV/MEAN	SCHEDULED	OBSERVED
Early	3 (38)	65	46	57	5.2	.09	1.41	1.14
AM Peak	2 (14)	80	64	72	8.8	.12	1.25	1.11
Midday	15 (43)	80	64	66	5.1	.08	1.25	1.21
School	2 (11)	90	64	72	7.8	.11	1.41	1.25
PM Peak	6 (40)	90	64	77	8.3	.11	1.41	1.17
Evening	3 (38)	60	46	60	5.7	.10	1.30	1.00
Night	3 (18)	60	46	51	6.3	.12	1.30	1.18
47.4								
AM Peak	13 (48)	50	42	44	4.5	.10	1.19	1.14
School	4 (40)	54	42	48	4.0	.08	1.29	1.13
PM Peak	10 (63)	54	42	53	9.7	.18	1.29	1.02

47.0 trip that takes 30.5 (24.9 + 5.6) minutes to go from Boston City Hospital to Sears (and one out of the seven will take at least this long), is followed six minutes later by the one-out-least this long, is followed six minutes later by the one-out-of-the-six 47.4 trips that traverses this segment in 21 (26.8 - 5.5) minutes or less, the latter will catch up to the former somewher around Ruggles @ Parker or 60% down the legnth of the route. Such potential for platooning occurs in the A.M., schooland P.M. peak periods when both variations operate.

Although highly variable running times contribute to uneven spacing and loading among buses, the schedule may do so as well. Peak period service is operated with irregular trunk headways, even though each variation has regular headways. The irregular headways contribute to uneven loading which, even if not too bad at the beginning of the trunk becomes more uneven as buses progress toward the end. The uneven loading can, in turn, cause the uneven gaps of scheduled headways to become more uneven as buses progress along the trunk.

There is uneven loading between short and long trips, and this is partly due to one group of travelers having to take 47.0, but some of the unèveness is due to uneven headways. As an example, in the P.M. peak outbound direction, long trips are preceded by 12 minute headways and short trips by six. By the time buses arrive at Sears, the average maximum load on long trips is 36while on short trips it is four. One-half the passengers on the long trips alight on the trunk, implying that they could take a short trip. Some of the travelers on the long trips, then, are on them because, even though they are indifferent to long versus short trips, they have a longer time to congregate at stops prior to long trips arriving than they do prior to short trips.

The uneveness of headways is more apparent in the inbound direction as long trips join the trunk at Sears. This is so because of the reliance on scheduled times that are not consistent with observed times. For instance, in the A.M. peak, 47.0 trips join the trunk an average of eight minutes behind 47.4 trips rather than five minutes as scheduled. Trunk headways then become two, eight and 10 minutes in succession rather than the scheduled five, five and 10 minutes.

Not all of the route's unreliability is attributable to its schedule and variable running times. A third source of information about the route is the field observations made during ridechecking, and they indicate that there was confusion regarding bus destinations which, in some cases, may have contri buted to a feeling of unreliability. Specifically, passengers were observed being confused about whether buses leaving Boston City Hospital were short or long trips. In some cases, this delayed the buses' departures. Signing on the buses was often inadequate and occasionally wrong, and at least one driver was unclear about where he was going. On at least two occasions,

several passengers who thought they were on a Central Square-bound bus found themselves having to alight at Sears, the last stop of the short-turns.

A final source of information about Route 47 is an on-board survey. Route 47, along with Route 66, was rated the least reliable in the corridor, by passengers responding to this survey. One-third of the route's survey respondents versus a corridor average of 18% rated the route below average in terms of whether one could count on getting to his destination on-time. Likewise, 43% of the route's survey respondents versus a corridor average of 24% rated the route below average in terms of whether buses come on schedule.

Cross-tabulating user characteristics with these attitudes about reliability yielded some interesting, if not operationally useful results. Those who ride Route 47 in peak periods and who access the route by transferring from another transit line had the harshest views. Likewise, those under 17 and over 65 years old and those riding less than 5 days per week were more critical than those in the middle age ranges and those who ride daily.

VI. Recommmendations

Route 47, again, operates in an environment that works against the maintenance of reliable transit service. Outside of large-scale changes such as the provision of exclusive transit lanes, the route must continue to face some degree of what is a commonly perceived indication of unreliability - namely, running time variability. However, other facets of unreliability can be addressed and the following suggestions may serve as guidelines.

A. Improve Public Information and Dispatching Practices

Even if no concrete changes were made to the route, passenger perceptions about unreliability could probably be improved by making it easier for them to get where they are going. First, the typical running times shown on the back of the public timetable should be updated to reflect observed running times from the ridechecking, which are greater than the scheduled times shown. Second, buses should be clearly signed as to their destinations. Third, some temporary field supervision might be considered, particulary at Boston City Hospital.

B. Scheduling Changes

More slack in the schedule at certain times of the day would give buses a greater chance of maintaining schedule. More slack is particularly needed in the following cases: A.M. and P.M. peak periods on both variations and evening service on 47.0. More even peak period trunk headways, to serve the objective of evening leads, may be worthwhile as well. Reducing overall

levels of crowding, as an attendant objective, should also be considered, where practical.

In the A.M. peak, the following strategy would serve the objectives of increasing slack, operating even trunk headways and lessening crowding as well. A vehicle would be added to each variation and headways would be reduced slightly.

	Vehicles		Headways		Actual Cycle/Run Time		Average Maximum Peak Direction Load	
Variation	Old	New	Old	New	Old	New	Old	New
47.0	4	5	20	18	1.11	1.25	50	45
47.4	4	6	10	9	1.14	1.23	49	44

This schedule would, based on statistical probability, ensure that succeeding trips in a driver run depart the terminal on-time at least 90% of the time. Operating the 47.4 on alternating six and 12-minute headways along with 47.0 on 18-minute headways would result in even trunk headways of six minutes. Loads would be a bit lower overall, as well as a bit more even among buses.

In the PM peak period, solutions are less straightforward. Adding schedule slack and evening headways cannot both be accomplished within the context of present demand. One solution is presented in the following table. It involves adding a vehicle to 47.4, thereby adding slack where it is most needed. Headways would remain constant on each variation, but trunk headways would be evened out to nine minutes.

	Vehicles		Headways		Actual Cycle/Run Time		Average Maximum Peak Direction Load	
Variation	Old	New	Old	New	Old	New	Old	New
47.0	5	5	18	18	1.17	1.17	36	36
47.4	3	4	18	18	1.02	1.36	42	42

This evening of headways and improvement of 47.4 schedule adherence implying as it does, an evening of loads, may indirectly help the 47.0 to maintain schedule better, even with no direct changes to it. Statistical probability indicates that succeeding buses on both variations, operating with these schedule characteristics would maintain schedule at least 90% of the time. Although loads would be evened somewhat, overall loads would not diminish.

An alternative to the above would entail injecting some more slack into the 47.0 schedule and adding another vehicle to 47.4 as above, but reducing the latter's headways to 15 minutes. Such a strategy is depicted below.

Variation	Vehicles Old	Vehicles New	Headways Old	Headways New	Actual Cyle/Run Time Old	Actual Cyle/Run Time New	Average Maximum Peak Direction Load Old	Average Maximum Peak Direction Load New
47.0	5	5	18	20	1.17	1.30	36	42
47.4	3	4	18	15	1.02	1.13	42	32

The advantage of this is that more slack would be given to each variation, and slightly more carrying capacity would be given to the most crowded portion of the line (14 trunk bus-trips versus the current 13). The disadvantage is that the trunk headways would not be even (as they are not now) and total carrying capacity on the 47.0 portion of the line west of Sears would diminish slightly. The latter would not be too serious though, given that P.M. peak maximim load points on 47.0 generally occur on the trunk.

The final suggestion regarding the route 47 schedule is that, regardless of what changes may be made to the P.M. peak schedule, the evening schedule's transition from peak service to night service occur more gradually. That is, the closer headways or higher vehicle commitment of the P.M. peak should be retained longer after 6:00 P.M. in order to create a scheduled cycle time of greater than 60 minutes in the first part of the period. Currently, the cycle and average round-trip running times are equal then, a fact that, combined with running time variability ensures that about 40% of the trips will be late, as indeed, 38% of them are.

C. Holding/Expressing Strategies

Assessing the benefits and disbenefits that mid-route holding or expressing strategies would have on Route 47 is beyond the scope of this memorandum, but with a route that seems to experience as much unreliability as this, no possibility for improvement should be overlooked. It is not clear that there are locations at which buses, as a practical matter, could be physically held or expressed, but the route should at least be included in any route level analyses of the issue that may occur.

APPENDIX E
SCHEDULE COORDINATION OF CENTRAL NORTH ROUTES

CTPS

State Transportation Building
10 Park Plaza, Suite 2150
Boston, MA. 02116-3968
(617) 973-7100

CENTRAL TRANSPORTATION PLANNING STAFF

MEMORANDUM

TO: Central North Bus Study Files December 19, 1986

FROM: Geoff Slater

RE: Schedule Coordination of Central North Routes

Introduction

In the Central North (CN) area, 37,500 of 71,200 daily bus passenger trips involve a transfer to or from the rail transit system, another bus, or both. Of these transfers, 19,400 are bus-to-bus transfers involving 56 different bus routes, and 7400 of which are among the 14 CN bus routes. Because over half of the trips involve transfers, the coordination of schedules to reduce transfer times could benefit existing passengers and possibly generate new ridership at little or no cost to the MBTA. In many cases, routes cannot be easily coordinated without changes in schedules that would make the route less efficient in other respects. In other cases, schedule coordination can be accomplished with only minor schedule adjustments. This memorandum briefly examines this latter type of schedule coordination.

Existing Transfer Patterns

The following table lists the fifteen CN route combinations with the highest transfer volumes. Route combinations where schedules could be coordinated by making only minor adjustments are shown in bold typeface. (For the other route combinations, either both routes operate at frequent headways, making deliberate schedule coordination unnecessary, or significant schedule changes would be required.)

Transfers Between CN Bus Routes

Rank	Routes	Daily Transfers	Transfer Location
1.	47 & 83	577	Central Square
2.	57 & 66	375	Union Sq, Allston
3.	**57 & 60**	**294**	**Kenmore Square**
4.	1 & 70	272	Central Square
5.	47 & 70	252	Central Square
6.	57 & 70	218	Watertown Square
7.	**47 & 91**	**162**	**Central Square**
8.	1 & 47	134	Central Square
9.	57 & 86	128	Union Sq, Allston
10.	1 & 83	122	Central Square
11.	**66 & 86**	**110**	**Union Sq, Allston**
12.	**57 & 65**	**108**	**Brighton Ctr**
13.	1 & 64	97	Central Square
14.	1 & 57	93	Kenmore Square
15.	**70 & 83**	**90**	**Central Square**

Coordination Possibilities

As can be seen in the table, most transfers between CN routes occur at Central Square, Union Square in Allston, and Kenmore Square. In Central Square, coordination of too many routes could worsen bus congestion problems by increasing the number of buses in Central Square at the same time. However, coordination of only certain routes could be accomplished without this impact. Based on current service levels, Routes 70 and 83, and Routes 47 and 91 could be coordinated with minor schedule adjustments.

In Union Square, transfers occur between Routes 57, 66 and 86. Routes 57 and 66 operate a frequent headways so that transfers between these routes already involve little wait time. Schedule coordinaton between Routes 57 and 86 on an all day basis would be difficult to achieve without major schedule changes. Routes 66 and 86, however, could be coordinated with minor adjustments.

In Kenmore Square, transfers occur in large numbers between Routes 57 and 60, Routes 57 and 65, and Routes 1 and 57. As with Routes 57 and 66, both Routes 1 and 57 operate at frequent headways, making deliberate schedule coordination unnecessary. In the case of Routes 57 and 60, schedules could be coordinated so that, depending upon time period, every second, third or fourth Route 57 bus would directly connect with a Route 65 bus. Further, since Route 65 buses alternate with Route 60 for most of the day, schedules for these routes could also be coordinated.

Headway Adjustments

In most of the cases mentioned above, minor headway adjustments would be necessary in some time periods. However, based upon observed running times and passenger loads, all could be accomplished without changing cycle times or vehicle requirements, or exceeding acceptable passenger loading standards. These adjustments would be as follows (based on Fall 1986 schedules):

Routes 57 and 60 With minor adjustments to headways on both routes, every third Route 57 bus could connect with Route 60 in the AM peak, mid-day and PM peak, every fourth bus in the school peak, and every second bus at night. To do so headways would be as follows:

	AM Peak	Mid-day	School	PM Peak	Night
Route 57					
Current	6	9	8	6	15
Adjusted	6	**10**	**7**	6	15
Route 60					
Current	17	30	28	18	30
Adjusted	**18**	30	28	18	30

Routes 47 and 91 With minor adjustments to both routes, all service from the AM peak through the end of the PM peak could be coordinated, and every third Route 47 bus could meet every Route 91 bus at night:

	AM Peak	Mid-day	School	PM Peak	Night
Route 47					
Current	20	20	18	18	20
Adjusted	20	20	**20**	**20**	20
Route 91					
Current	25	25	25	25	60
Adjusted	**20**	**20**	**20**	**20**	60

Routes 66 and 86 Every second Route 66 trips could be coordinated with every Route 86 trip on an all day basis:

	AM Peak	Mid-day	School	PM Peak	Night
Route 66					
Current	7.5	14	10	8.5	30
Adjusted	7.5	**15**	10	**9**	30
Route 86					
Current	18	30	18	18	60
Adjusted	**15**	30	**20**	18	60

Routes 57 and 65 Coordination between routes would be on the same basis as between Routes 57 and 60, except that every fourth Route 57 bus would meet every Route 65 bus during the PM peak, and that there is no night service on Route 65:

	AM Peak	Mid-day	School	PM Peak	Night
Route 57					
Current	6	9	8	6	15
Adjusted	6	**10**	**7**	6	15
Route 65					
Current	20	30	28	25	
Adjusted	**18**	30	28	**24**	

Routes 70 and 83 These routes could be coordinated at Central Square on an all day basis using current average headways:

	AM Peak	Mid-day	School	PM Peak	Night
Current					
Route 70	15	30	15	15	60
Route 83	15	30	15	15	60

APPENDIX F
ROUTE 66 UNRELIABILITY

CTPS

State Transportation Building
10 Park Plaza, Suite 2150
Boston, MA. 02116-3968
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CENTRAL TRANSPORTATION PLANNING STAFF

MEMORANDUM

TO: Central North Bus Files January 12, 1987

FROM: Geoff Slater

RE: Route 66 Unreliability

The MBTA has received a number of complaints concerning problems with unreliability and the bunching of buses on Route 66. On-board surveys conducted for this study also confirm that a higher than average number of passengers believe that Route 66 performs poorly.[1] This memorandum examines the causes of unreliability on Route 66 and recommends improvements.

In summary, current reliability problems are a function of high running time variability coupled with insufficient recovery time between trips at Dudley Station. The running time variability is a function of Route 66's operating environment, and little can be done to reduce it. However, the number of late departures resulting from insufficient recovery time can be significantly reduced by shifting excess recovery time from the Union Square end of the route to the Dudley end, or by increasing cycle times. During the mid-day period, a redistribution of existing recovery time should be sufficient; during the AM peak, school and PM peak periods, additional cycle time is needed.

1.0 Background/Overview

Route 66 operates between Union Square in Allston and Dudley Station in Roxbury. Except for reliability problems, the route performs well in other respects. It carries 9,100 passengers per day, making it one of the ten most heavily utilized routes in the MBTA system. Service is frequent (8 to 10 minute headways from 6:00 AM to 7:00 PM) and ridership is heavy in both directions. The route serves a number of different markets, the largest of these being trips to Parker Hill and Allston-Brighton from neighborhoods directly along the route (47 percent of all trips). In addition, a large number of trips (29 percent) are made from residences outside of the Central North area, most of which are also made to Parker Hill and Allston-Brighton, and also to Brookline. Although ridership is high,

[1] 44.4 percent of Routes 66's riders rated on-time performance as poor or very poor, and 33.7 percent rated reliability as poor or very poor. By comparison, ratings for the same categories for all other routes combined were 30.5 percent and 21.9 percent, respectively.

overcrowding is not a problem (except in the inbound direction between 7:00 AM and 8:00 AM) because boardings and alightings are well distributed along the route.

2.0 Running Time Variablity

Route 66 experiences a high degree of running time variability during most periods of the day. This running time variability is the primary cause of the gaps in service and the bunching of buses on the route. The areas and time periods in which running time variability is the highest, and thus delays the worst, are summarized below (complete information on all segments of the route during all time periods is contained in Appendix A).

Table 1
Time Periods and Locations in Which Most Delays Occur

	Segment	Mean Run Time (min)	STD (min)	Coeff. of Var.
Outbound				
PM Peak	Dudley-Brigham Circle	7.4	3.0	.41
Early Eve	Coolidge Corner-Union Sq.	7.7	4.2	.55
Inbound				
AM Peak	Brookline Vil.-Brigham Cir.	7.3	4.3	.59
Mid-day	Union Sq.-Coolidge Corner	9.9	3.0	.30
Mid-day	Brigham Cir.-Dudley	9.5	3.1	.33
School	Brookline Vil.-Brigham Cir.	8.2	3.0	.37
PM Peak	Union Sq.-Coolidge Corner	12.4	5.8	.47
PM Peak	Brigham Cir.-Dudley	9.6	3.3	.34
Night	Brigham Cir.-Dudley	7.6	3.1	.41

Most delays occur in the inbound direction (towards Dudley), and occur at various points along the route throughout the day. In the inbound direction, problems are most acute during the mid-day and PM peak periods, where delays occur between Union Square and Coolidge Corner, and between Brigham Circle and Dudley Square. During other periods, the most serious delays are "confined" to a single segment along the route. The impact of this running time variability is that although most Route 66 trips depart on time, many reach intermediate points early or late. An example of this can be seen in the ridecheck data collected for this study: during the AM peak period, 11 of 12 observed trips departed Union Square within two minutes of their scheduled times at intervals of seven to eight minutes. Actual running times to Dudley, however, varied from 18 to 44 minutes (compared to the "book" time of 24 minutes), resulting in seven arrivals more than five minutes off schedule, and three others at three to four minutes off schedule. Had all of these trips been observed on the same day, the resulting intervals at which Route 66 buses arrived at Dudley would have been from 4 to 17 minutes.

Along Route 66, this running time variability is primarily caused by traffic congestion, and considering the markets that the route serves, little can be down to avoid or prevent it. The present alignment of Route 66 serves existing heavy demand most directly, and no practical alternatives exist. Bus lanes are not feasible since the streets on which the route operates are not wide enough, nor is service frequent enough to warrant them. A holding strategy could be of some use, but an expressing strategy would be of doubtful benefit since, for the most part, traffic, rather than passenger volumes, govern the speed of Route 66 buses.[2] As a result of these constraints, there is little that can be done to reduce running time variability, and thus some degree of off-schedule performance along the route must be tolerated.

2.1 Late Departures

In addition to causing off-schedule performance along the route, the high degree of running time variability, coupled with insufficient recovery time, is the cause of most late departures. These late departures then combine with delays encountered further along the route to worsen on-time performance at intermediate points, and to increase the severity of buses bunching together and the gaps in service.

In Table 2, the time periods in which on-time performance fell below MBTA standards[3] are highlighted:

Table 2
On-Time Departure Performance Using MBTA Standards

	Early Morn	AM Peak	Mid-day	Schl Peak	PM Peak	Early Eve	Night
Outbound							
• # Trips > 5 Minutes Late:	0	0	**2**	**2**	0	**0**	0
• # Trips Early:[4]	0	0	**1**	**0**	0	**1**	0
• # Trips Observed:	3	12	**18**	**10**	9	**7**	8
• % On-Time	100%	100%	**83%**	**80%**	100%	**86%**	100%

[2] Holding/expressing strategies are the subject of separate work currently being conducted for the MBTA at RPI. As a result, they are not further explored in this analysis.

[3] 80 percent of all Route 66 peak period trips, and 95 percent of all off-peak trips should leave on-time (on-time being defined as 0 to 5 minutes late, with no trips leaving early) - MBTA "Service Policy for Surface Transportation," August 1977.

[4] Due to possible differences between driver and ridechecker watches, only reported early departures of three minutes or more are included.

Table 2 (Cont)
On-Time Departure Performance Using MBTA Standards

	Early Morn	AM Peak	Mid-day	Schl Peak	PM Peak	Early Eve	Night
Inbound							
• # Trips > 5 Minutes Late:	**0**	1	**0**	**0**	1	**0**	0
• # Trips Early:	**1**	0	**1**	**1**	0	**1**	0
• # Trips Observed:	**5**	12	**15**	**1**	9	**6**	9
• % On-Time	**80%**	92%	**93%**	**91%**	89%	**83%**	100%

For the six late departures that were observed, all were caused by extremely late arrivals on the preceeding trip, coupled with insufficient recovery time. Further, as indicated in Table 3, if a more stringent definition of lateness were applied, such as 0 to 3 minutes late, the incidences of delays caused by high running time variability being "carried over" to the next trip increase significantly (decreases in on-time performance are highlighted):

Table 3
On-Time Departures Using Three Minutes as a Standard

	Early Morn	AM Peak	Mid-day	Schl Peak	PM Peak	Early Eve	Night
Outbound							
• # Trips > 3 Minutes Late:	0	**2**	**3**	**4**	**2**	**1**	0
• # Trips Early:	0	0	1	0	0	1	0
• # Trips Observed:	3	12	18	10	9	7	8
• % On-Time	100%	**83%**	**78%**	**60%**	**78%**	**71%**	100%
Inbound							
• # Trips > 3 Minutes Late:	0	1	0	0	**2**	**1**	0
• # Trips Early:	1	0	1	1	0	1	0
• # Trips Observed:	5	12	15	1	9	6	9
• % On-Time	80%	92%	93%	91%	**77%**	**67%**	100%

On this basis, 16 departures were observed three or more minutes late. Of these, 14 were caused by delays on the preceeding trip coupled with insufficient recovery time between trips. In one case, cumulative delays were carried through five consecutive one-way trips on the same bus run. Most late departures occured in the outbound direction (12 of 16), and all but one of these late departures were caused by delays experienced on the inbound direction (towards Dudley). In addition, although not apparent from the table, 3 of the 4 late departures on the inbound direction were also caused by delays on the inbound direction. In these cases, the delays experienced two trips prior to that trip were carried through

both subsequent trips. Further, most of the early departures in the inbound direction (3 of 4) occured during periods in which late arrivals at Dudley were causing late departures in the outbound direction. Often, early departures such as these are caused by drivers departing slightly early in an attempt not to fall too far behind schedule further along the route, which would further indicate a need for additional recovery time at Dudley Station.

2.2 Recovery Times

In order to prevent lateness from being carried over from one trip to the next, as has been the case, additional recovery time needs to be provided during certain time periods. Recent work done by the MBTA[5] indicates that a reasonable objective for the amount of recovery time included in cycle-to-running time (CT/RT) ratios would be 1.5 times the standard deviation of a route's mean round trip running time, by time period.[6] Recovery times set at this level would insure on-time[7] departure performance of better than 90 percent for the first one-way trip of each round trip. However, use of this measure does not explicitly address the second one-way trip of each round trip, and in the case of Route 66, this is where most lateness occurs. As shown in Table 4, mean running times on Route 66 in the inbound direction have increased significantly since MBTA book times were last calculated. (In the outbound direction, similar increases have not occured - existing book times are close to observed values, and where differences occur, book times exceed observed times by one to two minutes. See Appendix B for additional schedule information.)

Table 4
Schedule Statistics-**Inbound**
(all figures are averages; time figures are in minutes)

	Early Morn	AM Peak	Mid-day	Schl Peak	PM Peak	Early Eve	Night
•Running Times							
a. Book Times	18	24	26	28	28	23	18
b. Observed	18	**27**	**31**	**35**	**34**	23	**22**
•Recovery Times							
a. Scheduled	7	7	10	5	6	5	11
b. Observed	7	**4**	**4**	**-2**	**0**	6	8
c. STD * 1.5	4	11	9	8	11	5	10

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[5] MBTA memorandum "A Proposal for Work in the Scheduling Area," Nigel Wilson, November 14, 1985.

[6] Using the formula: $1.5\sqrt{s^2_{out} + s^2_{in}}$

[7] Using this measure, on-time is defined a 0 minutes late, as opposed to the MBTA definition of 0 to 5 minutes late.

These longer running times have effectively reduced the amount of recovery time allocated at the Dudley end of the line. During the AM peak, mid-day, school peak, and PM peak periods, observed running times exceeded book times by, respectively, 3, 6, 7, and 6 minutes. During these periods, recovery times have been reduced to a point where a high level of on-time departure performance cannot be maintained. During the AM peak and mid-day periods, observed recovery times were between 56 and 67 percent of desired levels, and during the school and PM peaks, observed running times in the inbound direction exceeded book times to the extent that, on average, there was no recovery time at Dudley between trips. (It was during these latter periods that delays were observed to be carried through a number of consecutive trips.) To provide enough recovery time to insure at least 90 percent on-time departure performance (at 0 minutes late) for trips in both directions, recovery times should be set at 1.5 times the STD of the mean running time of one-way trips, by time period *and direction*, rather than 1.5 times the STD of round trips, by time period only. On this basis, cycle time statistics would be as follows (running time and recovery time statistics by direction are included in Appendix B):

Table 5
Schedule Statistics - **Fall 1986**
(all figures are averages; time figures are in minutes)

	Early Morn	AM Peak	Mid-day	Schl Peak	PM Peak	Early Eve	Night
•Cycle Times							
a. Fall '86 Sched	47	61	68	68	69	63	58
b. "Optimum"[8]	38	64	68	74	77	51	54
•Running Times							
a. Scheduled	34	47	50	58	58	46	34
b. Observed	34	**50**	**55**	**63**	**62**	45	**42**
•Recovery Times							
a. Scheduled	13	14	18	10	11	17	24
b. Observed	13	**11**	13	**5**	**7**	18	16
c. STD * 1.5	4	14	13	11	15	11	9
•CT/RT Ratios							
a. Scheduled	1.38	1.30	1.36	1.17	1.19	1.37	1.71
b. Observed	1.38	1.22	1.24	1.08	1.11	1.40	1.38

As can be seen from this table, adequate recovery time is already provided on a round trip basis in the early AM, mid-day, early evening and night periods. In the mid-day period (early AM and night), on-time departure performance was not observed to be a problem, however, during the mid-day and early evening periods, it was. During the mid-day period, the existing cycle time is

[8]Minimum level required to insure at least 90% on-time departure performance.

sufficient to insure a high level of on-time departure performance, but the distribution of recovery time between the two ends needs to be adjusted to provide more at the Dudley end of the route and less at the Union Square end. Currently, an average of 10 minutes is scheduled at Dudley, but due to increased running times, this has been effectively reduced to 4 minutes. To insure at least 90 percent on-time performance in the outbound direction, this needs to be increased to 8 minutes. At the Union Square end, an average of 8 minutes was observed; this could be reduced to 4 minutes in order to offset increases at the Dudley end. During the evening period, the cause of late departures could not be positively determined from the available data. However, it is likely that the delays were not caused by cycle time/recovery problems, and no adjustments appear necessary.

To provide the necessary amount of recovery time to eliminate most "carry over" lateness in the AM peak, school and PM peak periods, cycle times during these periods would have to be increased to 64 minutes, 72 minutes and 77 minutes, respectively. This could be done in either of two ways: (1) existing headways could be maintained, requiring that one additional bus be deployed on Route 66 during each of the periods; or (2) vehicle deployment could be held constant, requiring that headways be increased slightly. Following is a comparision of these alternatives:

Table 6
Cycle Time Adjustment Alternatives
(all time figures in minutes)

	Vehicles Required	Head-ways	Cycle Time	Recovery Time	Pk 1/2 Hr Max Load In	Pk 1/2 Hr Max Load Out	Expected On-Time Perf
AM Peak *(Recovery Time @ STD * 1.5 = 14 min)*							
a. Fall '84	8	7/8	61	11	54	68	86%
b. Add'l Bus	9	7/8	68	18	54	68	97%
c. Add'l Bus	9	7	63	13	50	63	92%
d. Inc Headways	8	8	64	14	57	73	93%
School Peak *(Recovery Time @ STD * 1.5 = 11 min)*							
a. Fall '84	7	9/10	68	5	49	40	75%
b. Add'l Bus	8	9	72	9	47	38	89%
c. Add'l Bus	8	9/10	76	13	49	40	96%
d. Inc Headways	7	10	70	7	52	43	83%
e. Inc Headways	7	11	77	14	58	47	97%
PM Peak *(Recovery Time @ STD * 1.5 = 15 min)*							
a. Fall '84	8	8/9	69	7	41	36	76%
b. Add'l Bus	9	8/9	77	15	41	36	93%
c. Add'l Bus	9	8	72	10	39	33	84%
d. Inc Headways	8	9	72	10	43	38	84%
e. Inc Headways	8	10	80	18	49	42	96%
f. Inc Headways	7	11	77	15	53	47	93%

During the AM peak, crowding already exists during the peak half hour, where maximum loads average 68 in the outbound direction. As a result, in order to improve on-time departure without worsening crowding, one additional bus would have to be deployed . At existing 7 and 8 minute headways, 18 minutes of recovery time would be provided, which should result in 97 percent of all AM peak Route 66 trips arriving at the end of the line in time to depart on its next trip at its scheduled time. If headways were reduced slightly to 7 minutes, 13 minutes of recovery time could be provided. In this case, 93 percent of all trips could be expected to leave as scheduled (0 minutes late), and crowding would be reduced slightly.

In the school peak, in order to insure at least 90 percent on-schedule performance, either one additional bus would be needed, or headways would have to be increased to 11 minutes. If one bus were added and existing schedules maintained, 96 percent of all school peak trips would be completed in time to depart on the next trip as scheduled. If headways were increased to 11 minutes, 97 percent of all trips would depart on schedule, but depending on the type of bus deployed[9], maximum load standards could be exceeded during the both the peak half hour and for the period as a whole (average maximum loads would be 58 in the peak half hour, and 50 for the period).

During the PM peak, better than 90 percent on-schedule performance could also be achieved by either adding one additional bus or by increasing headways to 10 or 11 minutes. If one additional bus were added, existing headways could be maintained and average maximum loads would remain at 39 in the peak half hour. Increasing headways to 10 minutes would increase average maximum loads about 20 percent (to an average of 49 passengers in the peak half hour), still within acceptable levels. Increasing headways to 11 minutes would increase average maximum loads to 53 in the inbound direction, which depending on the type of bus deployed, could exceed standards.

3.0 Conclusions/Recommendations

Two factors combined create most of the unreliability problems on Route 66: (1) a high degree of running time variability along various segments of Route 66 in both directions throughout the day, and (2) inadequate recovery time at Dudley during the AM peak, school peak, and PM peak periods. The running time variability experienced by Route 66 is a function of the environment in which the route operates, and little can

[9] Maximum average loads for the peak half hour @ 140% of seated capacity would be 49 for accessible RTS II buses, 56 for the non-accessible RTS II's, and approximately 64 for older buses.

be done to reduce it; therefore, some degree of off-schedule performance at intermediate points along the route must be tolerated. However, most of the terminal departure lateness now caused by the running time variability can be eliminated by either shifting existing recovery time from the Union Square end of the route to the Dudley end of the route, or by providing additional recovery time through cycle time increases.

Because little can be done to reduce the running time variability that causes the the bunching of buses and gaps in Route 66 service, the elimination of late departures should be given greater emphasis than usual as a way to reduce the severity of off-schedule performance along the route. To do so, schedules should be constructed to allow relatively more recovery time than for other routes, and to provide a higher level of on-time performance than required by MBTA standards. This would insure that delays experienced along the route were not compounded by late departures at the beginning of the route. On an overall basis, this would reduce the total amount of time lost to delays and thus improve reliability. On this basis, the following changes are recommended:

- AM Peak During the AM peak, crowding is a problem during the peak half hour (average max load: 68). In order improve reliability as well as reduce crowding problems, one additional bus should be deployed and headways reduced from their current 7.5 minute average to 7 minutes, allowing 13 minutes of recovery time per round trip. Assuming no other delays due to other causes, 92 percent of all trips would arrive in time to leave on the next trip as scheduled, and 5 percent would leave 1 to 5 minutes late.

- Mid-day The recovery times contained within existing cycle times should be redistributed to provide an additional 4 minutes of recovery time at Dudley Station.

- School Peak During the school peak, some crowding currently occurs on specific runs, but average maximum loads are within MBTA standards for both the peak half hour and for the time period as a whole. If cycle times were increased by lengthening headways, maximum loads for the school peak period could exceed MBTA standards (of 120% of seated capacity for the whole period), and maximum loads on individual trips could exceed 70 persons. To avoid this, one additional bus should be deployed with existing headways maintained. Again assuming no other delays due to other causes, 96 percent of all trips in this period would leave as scheduled, and 3 percent would leave 1 to 5 minutes late.

- PM Peak During the PM peak, improved reliability could be achieved and maximum loads kept within MBTA standards by

increasing headways from 8.5 minutes to 10 minutes. This would achieve 96 percent on-time performance, with another 3 percent leaving 1 to 5 minutes late.

Lastly, and as mentioned above, because of the nature of Route 66, a certain degree of unreliability will continue to exist. This analysis has identified the areas and times in which most problems will occur (see Section 2.0 and Appendix A). In many cases, passenger complaints can be reduced or avoided by explaining the nature of problems that will occur and by informing passengers when they are likely to occur. In addition, because running times vary significantly between periods (as well as within periods), informing passengers of approximate departure times from intermediate points along the route could also be useful, both to the MBTA in reducing complaints, and to riders in planning trips. Both types of information could easily be included on the schedule card for Route 66 at little or no cost.

Appendix A

Running Times by Route Segment and Time Period

Central North Bus Study
Route 66 Unreliability - Appendix A (Cont.)
Running Times by Route Segment and Time Period* (in minutes)

INBOUND	DUDLEY STA - BRIGHAM CIRCLE	BRIGHAM CIRCLE - BROOKLINE VILL	BROOKLINE VILL - COOLIDGE CRNR	COOLIDGE CRNR - UNION SQUARE	TOTAL ROUTE
Early Morning					
Mean Running Time	5.3	4.0	3.8	4.8	17.5
Standard Deviation	1.0	0.0	1.0	0.8	1.9
Coefficient of Variation	0.19	0.00	0.26	0.17	0.11
AM Peak					
Mean Running Time	7.3	7.3	6.2	6.5	27.3
Standard Deviation	1.3	4.3	1.6	1.6	6.9
Coefficient of Variation	0.18	0.59	0.26	0.25	0.25
Mid-day					
Mean Running Time	9.5	5.5	6.3	9.9	31.0
Standard Deviation	3.1	1.3	1.6	3.0	5.2
Coefficient of Variation	0.33	0.24	0.25	0.30	0.17
School Peak					
Mean Running Time	9.2	8.2	7.1	10.5	35.0
Standard Deviation	1.4	3.0	1.5	2.5	3.4
Coefficient of Variation	0.15	0.37	0.21	0.24	0.10
PM Peak					
Mean Running Time	9.6	5.6	6.0	12.4	33.6
Standard Deviation	3.3	1.2	2.2	5.8	4.1
Coefficient of Variation	0.34	0.21	0.37	0.47	0.12
Early Evening					
Mean Running Time	5.8	4.5	6.6	5.3	22.5
Standard Deviation	1.7	2.0	2.4	1.2	3.2
Coefficient of Variation	0.29	0.44	0.36	0.23	0.14
Night					
Mean Running Time	7.6	3.7	3.7	6.8	22.0
Standard Deviation	3.1	1.0	1.2	1.8	4.2
Coefficient of Variation	0.41	0.27	0.32	0.26	0.19

Appendix B

Route 66 Weekday Schedule Statistics

Central North Bus Study
Route 66 Unreliability - Appendix B
Schedule Statistics - Weekdays

Note: All figures are averages, in minutes.

	Early Morn	AM Peak	Mid-Day	School Peak	PM Peak	Early Evening	Night
Outbound							
Scheduled Run Time	16	23	24	30	30	23	16
Observed Run Time	16	23	24	28	28	22	20
STD of Obs Run Times	1.0	2.7	3.2	3.9	6.0	3.9	2.2
Scheduled Recovery Time	6	7	8	5	5	12	13
Observed Recovery Time	6	8	9	7	**5**	12	9
*STD * 1.5*	2	4	5	6	9	6	3
Inbound							
Scheduled Run Time	18	24	26	28	28	23	18
Observed Run Time	18	27	31	35	34	23	22
STD of Obs Run Times	1.9	6.9	5.2	3.4	4.1	3.2	4.2
Scheduled Recovery Time	7	7	10	5	6	5	11
Observed Recovery Time	7	**4**	**4**	**-2**	**0**	6	8
*STD * 1.5*	3	10	8	5	6	5	6
Round Trip							
Scheduled Cycle Time	47	61	68	68	69	63	58
Sched RT Run Time	34	47	50	58	58	46	34
Obs RT Run Time	34	50	55	63	62	45	42
Sch Cycle/Run Time	1.38	1.30	1.36	1.17	1.19	1.37	1.71
Obs Cycle/Run Time	1.38	1.22	1.24	1.08	1.11	1.40	1.38
Sch Recovery Time	13	14	18	10	11	17	24
Obs Recovery Time	13	**11**	13	**5**	**7**	18	16
*STD * 1.5 (In + Out)*	5	14	13	11	15	11	9

APPENDIX G
BUS ROUTE PRODUCTIVITY, EFFICIENCY AND RELIABILITY

CTPS

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CENTRAL TRANSPORTATION PLANNING STAFF

Memorandum

To: Central North Bus Study Files January 28, 1987

From: Karl H. Quackenbush

Re: Bus Route Productivity, Efficiency and Reliability

I. Introduction

In the Fall of 1984, 14 MBTA bus routes, constituting the Central North Corridor, were ridechecked. The purpose of this memorandum is two-fold: first, to present summary tables of the ridecheck information, and second, to set forth key findings about the performance of the routes and recommend changes, route-by-route, that would bring service within standards.

This memorandum is one in a series that deals with various aspects of Central North service. Others have examined market issues and various issues, such as reliability, that are a major concern with certain specific routes. The recommendations in this memorandum, then, are made almost solely from the perspective of performance. They are a repetition of recommendations presented in the route-specific memoranda, but they do not address market-based concerns: they assume that the basic design of the routes will be retained. A final memorandum will consolidate all recommendations into one comprehensive service plan.

Based on existing MBTA standards, Central North routes are productive and financially efficient.[1] Crowding is infrequent and on-time performance, while a serious concern on a few routes, is also generally within standards. The recommendations in this memorandum, then, are relatively minor in scope and largely involve adjustments to vehicles and headways. It should be noted, though, that a whole range of operating and design changes was considered when route weaknesses were uncovered. In most cases, these kinds of changes were deemed unnecessary or inappropriate.

[1] For more information on the service standards used here, see the 1977 MBTA document, Service Policy for Surface Public Transportation.

In sections II through VII, ridecheck information is presented. For ease in reading, all tables appear together after the narrative. While the chief features of the tables are pointed out, the information in them usually speaks for itself and is mainly intended to document Fall 1984 performance characteristics for future reference and to back up the recommendations. The latter are contained in Section VIII.

II. Route Productivity

Table 1 depicts productivity performance measures for all routes on an all-day, weekday basis. All-day weekday boardings in the corridor total roughly 71,000, with an average of 40 passengers per trip. On average, there are 8.6 passengers per revenue mile and 72.2 per revenue hour. All routes are above MBTA standards of minimum acceptable productivity. In Table 2, routes are depicted in rank order on the basis of the same three measures used in Table 1. Routes 60, 64 and 85 stand out as the weakest performers and Routes 1, 47, 66, 69 and 83 as the strongest.

Tables 3, 4 and 5 contain period-level productivity values on a per trip, per mile and per hour basis, respectively. Not surprisingly, the three most productive periods, by far, are the AM, school and PM peaks in descending order. Midday is next most productive in all three tables, followed by early service. Evening and night service is least productive.

Most of the productive routes are productive in all periods. One exception, shown in Table 5, is Route 47, which performs below average in the AM peak, due to relatively low performance on variation 47.4.

The high productivity of many Central North routes is influenced by their being heavily traveled in both directions all day. This, in turn, is largely due to these routes having rail stations at both terminals and often at intermediate points. (Those with rail stations at both ends are 20% more productive, as a group, than those with a station at only one end.)

III. Crowding

Table 6 contains load data for Central North routes. The table shows that crowding is concentrated on a handful of routes, generally during commuter and school peaks, as expected. Table 7 lists the most crowded routes and periods and is arranged in descending order on the basis of average maximum load during the peak half-hour for AM, PM and school peaks, and average maximum load during the peak hour for the midday period.

Routes 1, 47, 57, 66, 70 and 83 account for most instances of crowding. Four instances of peak-period service have average maximum loads high enough to exceed MBTA period-level standards: 70.0 AM peak, 47.4 school, 57.0 AM peak and 70.0 PM peak service. There are nine cases that exceed MBTA peak half-hour load standards, seven of which are AM peak. Not only is crowding concentrated in certain routes and time periods, then, but it is also concentrated within periods in the form of very high loads for short durations.

The midday cases cited in the table do not exceed standards or contain standing loads, on average, but they represent the highest average midday loads in the corridor.

IV. Financial Performance (Efficiency)

Table 8 contains financial performance measures for Central North bus routes. As shown, the overall corridor revenue-to-cost ratio is 0.88 and all routes perform well above the MBTA standard of 0.30 for regular routes. In fact, all but one route meets or exceeds 0.50 and all but two routes cover two-thirds or more of their operating costs. The table shows that the daily weekday cost of operating corridor buses is $30,137, while the daily revenue is $26,614. This leaves a daily operating deficit of $3,523 which translates into $3.94 per vehicle-trip and $0.05 per passenger-trip.

Three routes in the corridor - 57, 65, and 66 - actually generate more than enough revenue to cover their operating costs. In fact, Route 66 generates half again as much revenue as it costs to operate. Route 83 comes very close to breaking even.

In terms of net costs, Routes 1 and 70 are the most expensive, by far, to operate. The former has the most trips in the corridor, and the latter is one of the longest in the system. Routes 64 and 85, in keeping with their relatively poor boardings performance, are the poorest performers on the basis of farebox recovery and net-cost-per-passenger.

As would be expected, the financial performance of the routes is closely related to their boardings effectiveness in most cases. In some cases, though, this link is not strong. Route 65, for instance, although one of the strongest financial performers, due partly to its having very low cycle-to-running time ratios (hence, little excess cost), is only about average in boardings effectiveness (defined in terms of revenue vehicle hours, rather than total vehicle hours). Conversely, Route 69, which is among the best in boardings effectiveness, performs only just above average in financial efficiency, as it has quite a bit of unproductive time in its schedule.

Although variation in revenue is very closely associated with variation in boardings, it is not at all associated with variation in average fare, as is the case in some other corridors. This is because the average fare among Central North bus routes varies little - from $0.36 to $0.40. For perspective, the South Shore corridor local routes, when surveyed in 1984, had a range in average fares of from $0.30 to $0.53. The lack of variation in average fares among Central North routes is due to all but one of them being one-zone routes and to reduced fare-payers being more evenly distributed among routes than they are in the South Shore.

V. On-Time Performance

A. Late Terminal Departures

Table 9 lists the instances in which Central North service exceeds MBTA standards in terms of late terminal departures. These represent 16 percent of the route-by-period-and-direction cases that make up Central North corridor service. Note that those cases in which the number of trips later than five minutes is two or more are highlighted. These might be viewed as definite problem areas, whereas those listed having only one trip later than five minutes may have been the result of an unusual problem (traffic or mechanical, for example), not related to route operations. Although MBTA policy does not specify whether service should be judged on a variation and directional basis, as it is here, it seems appropriate, given that a traveler is usually only concerned with just that.

The table is dominated by both major variations of Route 47 and Routes 1, 65, 69 and 70. Overall, the PM peak period has the poorest performance on the basis of the highlighted, clear departures from MBTA policy. If the cases with one trip are included, then the midday period also stands out as troublesome.

B. Early Terminal Departures

Earliness is less of a problem than lateness in the Central North corridor. Trips reported to have left one minute early were discounted as insignificant or the possible result of measurement error. Instead, a summary of trips reported to have left terminals two or more minutes early was constructed and is shown in Table 10. Those listed represent eight percent of the total route-by-period-and-direction cases in the corridor.

A total of 53 early trips was recorded. Routes 1.0 and 57.0 registered the highest numbers - 20 and 19 respectively. Roughly 75 percent of the early trips are in the inbound

direction, typically departing from unsupervised terminals, and most are in the midday and school periods.

VI. Running-Time Variability

Table 11 lists observed running time measures by route, time period and direction. Running time variability is, of course, more meaningful within the context of recovery time, which will be discussed below. However, another implication of running time variability, perceived unreliability (as opposed to actual) is indicated by the information in Table 11. Headways are listed, and close headways combined with high variability, due to the increased likelihood of bus platooning, may cause passengers boarding mid-route to view service as unreliable. Such conditions occur, for example, on Route 57.0 AM inbound service. Long headways combined with high variability may also foster impressions of unreliability among passengers.

No analysis of these issues was done, and the analysis of possible strategies for minimizing running time variability, such as holding or expressing strategies, is outside the scope of this memo.

VII. Running Time, Recovery Time and On-time Performance

Table 12 contains running time, recovery time and on-time performance information. The information is presented for two reasons: to show the relationship between cycle and running times and to show the relationship between recovery time and on-time performance.

According to the measure "cycle/observed round trip run time", there are some places in the schedules that contain enough recovery time that cutting back on it, where logistically possible, would be desirable. Table 13 contains a subset of the information in Table 12. It lists all places where the cycle/observed round trip run time exceeds 1.30, in keeping with the threshold used in MBTA standards.

Table 12 also indicates places in the schedule where more recovery time may be desirable. Scheduled recovery time is compared to observed recovery time and required recovery time. The latter is based on scheduling one-way trips so that at least 90 percent of them, following the first one-way trip in a run, leave their terminals according to scheduled

leave times.[2] Table 14 contains a subset of all places where the required recovery time exceeds the observed recovery time. In almost all these cases, the observed running time exceeds the scheduled (book) time: the latter is often simply out-of-date. In most instances, though, even the scheduled recovery time is less than what is required.

Recovery time, as it affects on-time performance, is evident from the information in Table 12. To summarize, there are 27 places in the schedule where lateness was observed to occur, in one or both directions, according to standards. Of these, 18 or two-thirds of them were associated with one or more of the following: insufficient recovery time in the same period, insufficient recovery time in the preceding period (leading to "carry over" lateness), and an imbalance in recovery time allocation between terminals. That is, round trip recovery time may have been sufficient, but due to directional differences in running time and running time variability, more time than was scheduled may have been needed at one end of the route.

Of the one-third of the late cases not clearly associated with insufficient or imbalanced recovery time, two-thirds or six of them were deemed late on the basis of only one trip. Thus, there was more potential for an unusual occurrence, such as a vehicle breakdown, to cause service to depart from standards in these cases. The remaining one-third or three cases were late due to a grossly late-running driver in each. These three were: 65.0 PM peak, 69.0 PM peak and 69.0 night period service.

There is evidence in Table 12 that some earliness is also linked to insufficient recovery time. There are 14 places in the schedules where earliness occurred, in one or both directions, according to MBTA standards. Of those, seven or one-half were associated with insufficient round trip and/or directional recovery time. This may have compelled drivers, particularly at unsupervised terminals, to leave early in order to make the next one-way trip on time.

Of the seven cases of earliness that are not clearly linked to schedules, four of them were at unsupervised terminals and were at times when the cycle/observed round trip run time was less than 1.20, indicating that drivers may have felt compelled to leave early due to their fear of falling behind schedule.

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[2] This is calculated as follows: required recovery time at one terminal = 1.3 X standard deviation of observed one-way running time. The value 1.3 coincides statistically with an on-time probability of 90.32%. Required round trip recovery time is simply the sum of that required at each terminal.

VIII. Discussion, Summary and Recommendations

This section contains a summary of key findings along with recommendations for boosting low productivity, easing crowding and optimizing schedules. A limited amount of analysis is presented when necessary to support a particular recommendation. Schedule changes are the focus here, but design changes, to a route's length for instance, are suggested in a couple of instances.

Recommendations are based on one reading of the data. It is understood that MBTA personnel, with their knowledge of MBTA scheduling practices and constraints, may see different solutions from those suggested. This may happen particularly in cases where a judgement is clearly being made. For instance, such things as "basic minimum levels-of-service" and the advisability of keeping clock-face headways are discussed not in terms of standards (which, of course, do exist in the form of general statements), but in terms of the analyst's judgement.

The recommended schedule changes assume continued use of manual, rather than computerized run-cutting. Since almost no interlining occurs now in the Central North corridor, and since instituting it manually for large groups of routes is so difficult (assuming that particular schedule pairs are even compatible enough), it is assumed that when a given route has what might be termed "excess" or "insufficient" cycle (allowed) time, fixing it by shifting a few minutes of platform time between that route and another is usually not practical. In other words, the recommendations assume that minor changes to fix imbalances between cycle and running times must be made wholly within the schedule of that route alone. (However, opportunities for larger shifts of resources among routes, such as a whole vehicle, <u>are</u> addressed.)

Furthermore, there are often no clear net benefits associated with making minor changes to one route's schedule when, for instance, it appears to have more cycle time than needed. It is often deemed that the route's schedule currently represents the most sensible, "best fit" of vehicles and headways to a given route's length, span of service and demand. That is, the schedule may already represent an upper- or lower-bound level of service for the existing demand, or it may now provide desirable clock-face headways. In sum, it is often just not clear that platform time either can or should be "squeezed out" of a schedule for use elsewhere; a lowered cycle-to-running time ratio, unless it results in better service or a savings in operator resources, is meaningless.

It was originally intended that this analysis be done soon after data were collected. But since this was not the

case and since more recent data are not available, the recommendations are based on 1984 data, except where noted (cost data are from 1986). Any changes made to service since 1984 are noted parenthetically after each recommendation. It is assumed that spot checks of current conditions would be made before any changes to service are implemented.

Finally, since bus service performance was largely evaluated with respect to the standards that exist in the 1977 MBTA document, Service Policy for Surface Public Transportation, it is strongly recommended that these standards be re-evaluated for their reasonableness with respect to current conditions and policies.

Following is a summary of general findings followed by findings and recommendations relating to each route specifically.

A. Summary of General Findings:

Nearly all Central North bus service is above minimum acceptable productivity standards.

Nearly all Central North service is within maximum load standards.

Crowding is concentrated on certain routes during peak periods and is of short duration.

All Central North service is above standards for farebox recovery.

Scheduled (book) times are frequently no longer valid.

Many instances of service exceed the 1.30 cycle-to-running time standard (45, or 44%, of the total route-by-period cases). Much of this is associated with scheduled running times exceeding observed running times (62% of the 45 cases).

There are several places in the route schedules where more than the observed recovery time is needed, based on statistical probability (26, or 25%, of the total route-by-period cases). In 40% of these cases, scheduled recovery time would be sufficient, but for the fact that observed running times exceed scheduled running times.

Due to directional differences in running time variability, the recovery time required at two ends of a route can vary considerably.

On-time performance problems are largely a reflection of insufficient cycle time. Sixteen percent of the Central North cases exceed the standard for lateness. Eight percent of them exceed the standard for earliness.

B. Route-specific Findings and Recommendations

For each route, significant findings are enumerated along with "bulleted" recommendations. All recommended changes are summarized in Table 15.

Route 1 Harvard Square - Dudley

Finding: This route is productive in both directions and in all time periods. It carries 15,735 passengers per weekday, making it, by far, the most utilized route in the corridor. There are relatively many standees in the AM, PM and school peaks - approximately 200 passengers stand through the peak direction peak load point in each period - but in no case are standards exceeded.

- Retain current headways.

Finding: On-time performance is a problem. PM peak and evening lateness is linked to insufficient cycle time. Inbound earliness is largely due to drivers disagreeing as to which stop in Harvard Square is the correct terminal.

- Address PM peak and evening late dapartures by increasing PM peak cycle time by seven minutes. Do so by adding one vehicle. (This was subsequently done.)

- Instruct all drivers that Mass Ave and Holyoke is the correct terminal in Harvard Square and follow through with some field supervision.

Finding: Although the evening cycle-to-running time ratio does not exceed 1.30, the cycle time could be reduced from 85 to 77 minutes without risking late departures, and this would allow one vehicle to be dropped.

- Drop one vehicle from the schedule. (Actually, one vehicle was subsequently added here.)

Route 47 Central Square - Boston City Hospital

Finding: Both variations of this route are very productive. However, peak half-hour load standards are exceeded in three cases: 47.0 AM peak, 47.4 AM peak and 47.4 school peak. (Period average loads are within standards.)

• 47.0 AM peak: With four buses on 20-minute headways, the peak half-hour load is 65. Add one bus and shorten headways to 18 minutes to decrease the load to 57-60.

• 47.4 AM peak: With five buses on 10-minute headways, the peak half-hour load is 70. Add one bus and shorten headways to nine minutes to decrease the load to 60-64.

• 47.4 school: With three buses on 18-minute headways, the peak half-hour load is 73. Adding one bus and shortening headways to 15 minutes would only decrease it to about 66. So, send out an extra inbound trip between 3:39 and 3:57 in order to reduce the loads then to about 50.

Finding: Much lateness exists on the route, not all of which is related to scheduling. Passenger and some driver confusion as to bus destinations leaving Boston City Hospital was observed during ridechecking and this contributed to late departures. However, four periods on 47.0 and one on 47.4 do need more cycle time to reduce lateness. The issue of Route 47 reliability is treated in-depth in the CTPS memorandum "Route 47 Unreliability," K.H. Quackenbush, September 19, 1986.

• 47.0 AM peak: The above change to reduce crowding would also increase cycle time by 10 minutes, sufficient to eliminate most lateness. However, more of the recovery time should be allocated to the Dudley than to the Central Square end of the route, due to directional differences in running time variability. This change would also reduce "carry-over" lateness in the midday period.

• 47.0 and 47.4 PM peak: Add one vehicle to the three on 47.4, thus adding 18 minutes to the cycle time, and even out trunk headways to improve reliability on both variations. (See "Route 47 Unreliability" for details on the effect of uneven headways on loads and reliability.) This change would also reduce "carry-over" lateness in the evening period.

• All periods: Better dispatching at Boston City Hospital and clear destination signs would improve on-time performance and perceived reliability.

Route 57 Watertown Square - Kenmore Square

Finding: This route is fairly productive and among the most financially efficient. AM peak service, though, is very crowded and in need of more cycle time to reduce earliness then and lateness in the succeeding period.

• With 11 vehicles operating on six-minute headways, the period average maximum load is 60 and the peak half-hour load is 69. Adding one vehicle or lengthening headways one minute would provide sufficient cycle time, but to bring loads within standards, add three vehicles and shorten headways by one minute.

Finding: There is much inbound earliness which is not linked to the schedule.

• Improve dispatching at Watertown Yard.

Finding: School and evening period service has more cycle time than is needed to maintain on-time departures.

• Drop one vehicle from each period while keeping headways constant. Cycle time in both would become 64 minutes, more than enough to maintain on-time departures. Cycle-to-running time ratios would be 1.23 and 1.25 respectively.

Route 60 Chestnut Hill - Kenmore Square

Finding: This route is among the least productive in the corridor, but within productivity standards. The short-turn variation to Cypress and High Streets, 60.1, is distinctly less productive than the others during the periods in which it operates. See the CTPS memorandum, "Bunching of Buses on Brookline Avenue," K.H. Quackenbush, September 19, 1986 for a detailed examination of 60.1 productivity and the effects of its elimination.

• Eliminate variation 60.1 due to its low productivity. Remaining variations would become more productive as they absorbed its riders.

• To accomodate 60.1 riders without causing 60.4 loads to exceed standards, shorten the latter's headways from 20 to 15 minutes in the AM peak and from 25 to 20 minutes in the PM peak period. One vehicle would have to be added in the AM peak, but not the PM peak. (In the winter 1986 timetable,the MBTA did eliminate 60.1, add a vehicle to each peak, and shorten headways by three and seven minutes in the AM and PM peaks, respectively.)

Finding: Excess cycle time appears to exist in 60.0 midday, evening and night service and in 60.4 PM peak service. In all cases, book times are greater than observed times.

• 60.4 PM peak: Cycle time would be reduced from 75 to 60 minutes, if the headway is changed as suggested above.

• 60.0 midday: Two vehicles are used in the morning and three, interlined with Route 65, are used after 12:00 noon. This creates excess cycle time on 60.0, but not enough on 65.0. Route 65 needs eight minutes more recovery time and 60.0 could do with eight minutes less than observed. Therefore, shift eight minutes from 60.0 to Route 65 cycle time after 12:00.

• 60.0 evening: Retain current schedule. A vehicle cannot be eliminated without doubling headways and nothing would be gained by shortening the existing clock-face headways because the average maximum load is only 15 and service is not interlined then so that cycle time could possibly be "shifted" to another route.

• 60.0 night: Retain current schedule. Enough slack exists that a one-mile extension or deviation could be added to the route. However, market data do not suggest a need for such a change. Headways provided by the one vehicle are more than adequate for the demand, and the route is not interlined at night, so nothing would be gained by shortening headways within the existing span of service.

Route 63 Cleveland Circle - Central Square

Finding: The route is below average in productivity, but above minimum standards. This is one of a few routes on which a vehicle could be eliminated and headways lengthened significantly in peaks (from 20 to 30 minutes) without causing loads to exceed standards. (Maximum loads would average 45 in the AM peak, 36 in the school and 40 in the PM peak.)

• Despite this finding, 20-minute headways should be retained in the peaks to provide a basic minimum level of service.

Finding: The route segment from Western Avenue at North Harvard Street to just before Central Square in Cambridge is lowly patronized, which contributes to the route's lackluster performance.

• Retain alignment. It is the most logical one if the route is to continue to serve Central Square.

Finding: Lateness in the PM peak outbound direction exceeds standards. Book and observed times are equal, but required recovery time is two minutes more than either scheduled or observed and inbound trips need much more than outbound.

• Change existing 20-minute headways to 21 minutes. This eliminates clock-face headways but adds three minutes to the cycle time, eliminating almost all late departures. Allocate six minutes of recovery time to Central Square and three minutes to Cleveland Circle.

Finding: Excess cycle time appears to exist in the midday, not because book times exceed observed times (the reverse is true), but simply because the two vehicles on 30-minute clock-face headways create a cycle time of 60 minutes, compared to a minimum required one of 50 minutes.

• Retain current schedule: Headways could be shortened from 30 to 25 minutes to reduce cycle-to-running time ratio, but this would actually add 10 minutes of platform time to the schedule, assuming the same span of service.

Route 64 Oak Square - Central Square

Finding: The route is among the poorest in productivity. Like Route 63, one vehicle could be eliminated from AM and PM peak service and headways could be lengthened from 20 to 30 minutes without causing maximum loads to exceed standards. (They would average 44 in the AM and 41 in the PM peak period.)

• Notwithstanding this, 20-minute headways should be retained as they represent a rather lower-bound peak period level of service. Furthermore, it is not clear, using a range of possible elasticities, that productivity would be more than marginally enhanced by a lengthened headway.

Finding: Midday service exceeds lateness standards, but not because of the schedule. In fact, cycle time is much greater than needed. The lateness was caused by one trip departing late for some unknown reason.

• No change is recommended.

Finding: PM peak cycle time appears to need five additional minutes to ensure on-time departures, but service was on-time when observed. Book time and observed time is essentially equivalent.

• Retain current schedule. In this case, the calculated theoretical required recovery time is apparently not needed.

Finding: Cycle times appear to be excessive in most periods as indicated by cycle-to-running time ratios exceeding 1.30 in four out of five periods. However, book times and observed times are not that far apart. Rather, the "best fit" of vehicles and clock-face headways to the route creates the high ratios.

• Retain current schedule. Vehicles cannot be eliminated without greatly degrading levels-of-service. It is not clear that anything would be gained, other than reduced cycle-to-running time ratios, by shortening headways slightly. Crowding is not a problem and clock-face headways would be destroyed.

Route 65 Brighton Center - Kenmore Square

Finding: On-time performance standards are exceeded in the AM peak, midday and PM peak periods. In the first two, there is not enough cycle time, because observed times exceed book times by ten and seven minutes respectively. In the PM peak, more than enough cycle time exists, but one driver running late, for unknown reasons, created the problem.

• AM peak: retain current schedule for now, but shift any recovery time that exists on individual trips to Kenmore Station to help reduce the lateness, all of which is outbound. The problem, caused by one out of six outbound trips departing late, is not serious enough to warrant adding a vehicle. However, sufficient cycle time could be created by increasing headways from 20 to at least 23 minutes. Since doing so would cause already high loads to rise to just below standards and destroy clock-face headways, it is not clear that, on balance, service would improve. New data should be collected since the elimination of 60.1, which shared its trunk in the peaks, may have affected its running time.

• Midday: shift more cycle time from 60.0 to 65.5 in the latter part of the period when they are interlined, as explained previously under Route 60 recommendations. (The

MBTA addressed this problem by adding two minutes to the headways in the winter 1985 timetable.)

• PM peak: retain current schedule and monitor service to see whether lateness recurs.

Finding: PM peak cycle time appears to be 11 minutes more than it needs to be, creating a 1.39 cycle-to-running time ratio.

• Retain current schedule. The 25-minute headways could not be set at less than 21 minutes if on-time departures were to be ensured. There is no clear benefit in destroying clock-face headways to reduce the cycle-to-running time ratio. In addition, demand does not warrant more service, although demand, as well as running times, should be reevaluated since the elimination of 60.1.

Route 66 Union Square, Allston - Dudley Square

Finding: AM peak service is crowded.

• To bring loads within standards, add two vehicles to the eight currently used and shorten headways by two minutes from eight to six minutes.

Finding: Although on-time performance in several periods is within standard, it is just barely so, and more cycle time would be beneficial. See "Route 66 Unreliability," CTPS memorandum, G. Slater, January 12, 1987, for an analysis of problems and details of recommended changes.

• Midday: Cycle time is more than sufficient, but four minutes of recovery time should be shifted from Union to Dudley Square.

• School: Add one bus and maintain existing headways.

• PM peak: Lengthen headways from 8.5 to 10 minutes.

Finding: Cycle-to-running time ratios exceed 1.30 in four periods.

• Early and Evening: Retain current schedule for lack of workable alternatives and because service in these periods would be affected by the changes suggested above.

• Midday: Retain current schedule. The cycle-to-running time ratio is only 1.31, not far above standards, and headways are 12 minutes, providing an even five trips per hour.

• Night: Retain current schedule. Two vehicles on 30-minute headways provide service at night. This should be maintained to provide a basic minumum level of service. In the absence of another route with which to interline service, there is enough slack that the route could be extended by nearly one mile. Market data do not indicate a need for such an extension now, but it may be worth experimenting with in the future.

Route 69 Harvard Square - Lechmere Station

Finding: The average maximum load in the peak half-hour of the AM peak period is 66, in excess of standards. The average maximum load over the period is within standards at 52.

• Provide an additional outbound trip between 7:40 and 8:10. (In the fall 1986 timetable, the MBTA added one vehicle and reduced headways by five minutes for the whole period, a change that, if running time remained constant since 1984, created a cycle-to-running time ratio of 1.45. Loads, if they also remained at Fall 1984 levels, would not have required this additional service. (Other factors must have dictated the change.))

Finding: On-time performance problems exist in several periods, but in no case is there a lack of cycle time. Early inbound departures probably result from disagreement among drivers as to which stop in Harvard Square is the correct terminal. PM peak and night lateness was caused by one driver in each running late for an unknown reason.

• Make clear to all drivers that Mass Ave at Holyoke is the correct Harvard Square terminal.

• Monitor route to see whether some factor, not clear from the analysis, contributes to lateness.

• In one period, the evening, significantly more recovery time is needed at Lechmere than at Harvard. Eight and three minutes, respectively, should be allocated.

Finding: Cycle-to-running time ratios are high in all periods and exceed 1.30 in five out of seven periods.

• School: Reduce vehicles from four to three. This will not require headway lengthening. Cycle time will go from 50 to 38 minutes, the minimum required for 90% on-time departures.

• Early and Night: Retain current schedules. One vehicle on 30-minute headways operates in each, representing the best fit of vehicles and headways in providing a basic minimum level of service.

• Midday: Retain current schedule. Headways could be changed from 20 to 18 minutes, but loss of clock-face headways for the sole purpose of reducing the cycle-to-running time ratio is not clearly beneficial. (In the fall 1986 timetable, midday and PM peak headways were lengthened by 2.5 and three minutes, respectively. It is not clear from 1984 load and time data why these changes were made.)

Route 70 Cedarwood - Central Square

Findings: Both period-average and peak half-hour load standards are exceeded in 70.0 AM and PM peak periods. See "Route 70 Analysis," CTPS memorandum, K.H. Quackenbush, July 11, 1985, for an analysis of crowding and alternatives for relieving it.

PM peak 70.0 service needs five more minutes of cycle time to reduce lateness then and it needs more time at the inner than the outer end.

• Eliminate the 70.2 peak-period short-turn to Watertown Square and change 70.0 peak service by adding two vehicles and shortening headways by five minutes. As shown in "Route 70 Analysis," this will reduce crowding, enhance productivity, slacken the tight PM peak schedule and minimize passenger wait time. Also, allocate more of the recovery time to Central Square than to Cedarwood. (The MBTA made this change in the fall of 1985 and also added a vehicle and shortened headways in the school period.)

Finding: Midday 70.0 service has a cycle-to-running time ratio of 1.35 even though the observed time of 89 minutes is five minutes greater than book time. Service is operated with four vehicles on 30-minute headways.

• Retain present schedule. It represents the most sensible "fit" of vehicles and headways to the route.

Finding: School and evening service exceeds on-time performance standards. In the former, the cause is not clear as cycle time is sufficient. Evening lateness carried over from the PM peak would be reduced by the above-recommended PM peak schedule change.

- None.

Route 83 Rindge Avenue - Central Square

Findings: Loads during the peak half-hour of the AM peak average 64, in excess of standards. Average peak loads during the entire period average 47, within standards.

Cycle-to-running time ratios in the midday, school, PM peak and night periods exceed 1.30. In all cases, observed times are less than book times.

- Here is one case where it is clear that 1984 data are no longer useful. Since the Fall of 1984, the Red Line extension to Alewife opened, and Route 83 loads were known to have been reduced as a result. Consequently, running times may also have been reduced. However, the magnitude of these changes in unknown, and prior to any changes being made to the route, follow-up load and running time data should be collected. (In the spring of 1986, the route's peak period schedules were changed. Headways were lengthened by five and three minutes in the AM and PM respectively, and one vehicle was eliminated from the latter. Since the new AM peak cycle time is 90 minutes, 30 minutes more than used to be needed to ensure departures as scheduled, two vehicles could probably be dropped.)

Route 85 Spring Hill - Kendall Square

Findings: This route is the least productive in the corridor.

Cycle-to-running time ratios exceed 1.30 in four out of five periods.

- Retain current schedule. The route is served by one vehicle at all times and no other routes operate out of Kendall Square with which a vehicle could be shared, so the vehicle committment to the route is fixed for now. There is little point in changing headways, as demand does not warrant more frequent service. Conversely, service is at a basic minimum level already (30-40 minute headways throughout the

day). Minor reroutings, in already transit-saturated Somerville, are not worth trying. This route is simply fundamentally less productive than most, but since it is above standards, it should not be eliminated. A major rerouting, done to serve market-based objectives, would probably have the effect of enhancing its productivity. (See the CTPS memorandum, "Central Square/Kendall Square Bus Service," G. Slater, December 19, 1986, for an analysis of potential new service in East Cambridge and Somerville, some of which could replace Route 85.)

Route 86 Union Square, Allston - Sullivan Square

Finding: Although service in the PM peak is on time, and observed recovery time is sufficient, the schedule could be improved by allocating more recovery time to Sullivan Square than to Union Square.

- Allocate seven minutes to Sullivan and five to Union Square.

Finding: In five out of seven periods, cycle-to-running time ratios exceed 1.30. In three of those five, book times exceed observed times, but the high ratios are not generally due to these differences: even the cycle-to-scheduled running time ratios are high.

- AM peak: Retain current schedule. The cycle-to-running time ratio is 1.32, not much above standard, headways are clock-face now at 15 minutes, and the five vehicles must be retained to provide on-time service. (The MBTA, in the spring of 1985, lengthened headways and dropped one vehicle, a change that will have increased already high maximum loads, unless patronage decreased since 1984.)

- School: Change service from four vehicles on 20-minute headways to three vehicles on 22-minute headways. Headways would be non-clock face, but one vehicle would be saved for use elsewhere. Alternatively, enough slack exists that service could be extended to Brighton Center, providing direct Brighton-to-Harvard Square service. (In the spring 1985 timetable, the MBTA shortened headways by two minutes.)

- Midday and Night: Enough slack exists that buses could run to Brighton Center, thereby using them more efficiently and providing direct Brighton-to-Harvard Square service, at least for part of the day. (A vehicle was subsequently dropped from the midday in the spring of 1985, creating a cycle time of 60 minutes, four minutes less than required for on-time departures.)

Finding: Inbound service in the midday and night periods is late based on one in 10 trips in the former and one in four in the latter. In both cases, cycle times are more than sufficient. The cause of lateness is unknown and possibly these are isolated occurrences.

- No change is recommended.

Route 91 Central Square - Sullivan Square

Finding: Outbound school service exceeds standards for earliness. The schedule is not clearly the cause because the cycle time of 45 minutes is precisely what is needed to ensure that 90% of trips depart on schedule even though only 85% did so.

- No change is recommended.

Findings: Cycle-to-running time ratios exceed 1.30 in four out of seven periods. Productivity, while well above standards, is average for the corridor. Certainly, crowding is not a problem.

- This route's schedule could be legitimately left alone, given its productivity. However, it is suggested that a vehicle be dropped from the AM, midday, school and PM peak periods and that headways be lengthened by five minutes in order to free capacity for use elsewhere in the system. (In the winter 1986 timetable, the schedules were modified by dropping a vehicle in each period and lengthening headways by 10 minutes, which seems excessive, given that the same number of vehicles could provide 20- instead of 25-minute headways.)

Route	One-way Trips	One-way Length	Boardings	Boardings/ Trip	Boardings/ Mile	Boardings/ Hour
1.0	267	6.0	15735	58.9	9.8	83.7
1.1	4	6.9	126	31.5	4.6	50.4
1T	271		15861	58.5	9.7	83.2
47.0	107	5.2	5731	53.6	10.3	84.4
47.4	56	3.2	2032	36.3	11.5	84.0
47T	163		7763	47.6	10.6	84.3
57.0	253	5.5	9942	39.3	7.2	71.1
60.0	66	5.1	1362	20.6	4.1	41.4
60.1	18	2.8	308	17.1	6.2	43.4
60.2	1	1.2	1	1.0	0.8	10.0
60.3	5	3.5	NA	NA	NA	NA
60.4	19	4.6	702	36.9	8.1	66.2
60T	109		2373	21.8	4.8	45.9
63.0	71	4.5	2182	30.7	6.9	61.8
63.1	12	5.5	180	15.0	2.7	32.1
63T	83		2362	28.5	6.2	57.8
64.5	70	4.4	1540	22.0	5.1	45.2
65.0	58	4.1	1899	32.7	8.0	58.8
66.0	191	3.9	9149	47.9	12.4	80.8
69.0	119	2.5	3390	28.5	11.6	83.3
70.0	86	9.6	5328	62.0	6.5	66.2
70.2	26	4.3	576	22.2	5.2	46.8
70.3	2	7.2	NA	NA	NA	NA
70T	114		5904	51.8	6.2	63.0
83.1	106	3.4	4468	42.2	12.3	91.7
85.0	40	2.4	449	11.2	4.7	35.6
86.6	92	4.6	3260	35.4	7.7	56.7
91.0	110	2.6	2339	21.3	8.3	62.0
Total/ Average:	1779		70699	40.0	8.6	72.2
MBTA Std.					(peak) 2.5 (off-peak) 1.5	30.0

Central North Bus	BOARDINGS PERFORMANCE SUMMARY WEEKDAY	CTPS
Technical Memorandum KHQ 1-28-87		TABLE 1

Route	Boardings/ Trip	Route	Boardings/ Mile	Route	Boardings/ Hour
1	58.5	66	12.4	83	91.7
70	51.8	83	12.3	47	84.3
66	47.9	69	11.6	69	83.3
47	47.6	47	10.6	1	83.2
83	42.2	1	9.7	66	80.8
57	39.3	91	8.3	57	71.1
86	35.4	65	8.0	70	63.0
65	32.7	86	7.7	91	62.0
63	28.5	57	7.2	65	58.8
69	28.5	63	6.2	63	57.8
64	22.0	70	6.2	86	56.7
60	21.8	64	5.1	60	45.9
91	21.3	60	4.8	64	45.2
85	11.2	85	4.7	85	35.6
Mean	34.9		8.2		65.7
Median	34.1		7.9		62.5

Central North Bus	ROUTE RANKINGS BOARDINGS PERFORMANCE WEEKDAY	CTPS
Technical Memorandum KHC 1-28-87		TABLE 2

Route	Early	AM Peak	Mid-day	School	PM Peak	Evening	Night	All Day
1.0	33.9	71.3	63.0	84.2	72.0	31.4	32.8	58.9
1.1							31.5	31.5
1T	33.9	71.3	63.0	84.2	72.0	31.4	32.6	58.5
47.0	35.3	71.2	64.3	68.1	58.1	29.1	31.6	53.6
47.4	21.8	34.3	40.5	46.3	35.1	30.0		36.3
47T	31.2	46.2	62.8	58.0	47.5	29.2	31.6	47.6
57.0	40.4	62.7	35.1	46.5	41.5	27.7	22.6	39.3
60.0	22.1	38.5	21.1	32.8	44.0	16.4	7.8	20.6
60.1		18.4	3.0	18.0	17.5			17.1
60.2						1.0		1.0
60.3								
60.4		38.0			35.8			36.9
60T	18.1	30.2	20.3	31.5	28.1	13.5	6.8	21.8
63.0	15.4	43.0	27.3	33.4	40.2	16.7		30.7
63.1						48.0	12.0	15.0
63T	15.4	43.0	27.3	33.4	40.2	21.1	12.0	28.5
64.5	21.7	34.8	14.6	23.3	26.6	14.9		22.0
65.0	23.0	37.6	27.0	42.8	36.3	18.3		32.7
66.0	24.4	65.8	52.1	62.2	49.0	35.6	19.0	47.9
69.0	23.4	46.4	28.2	35.8	36.3	12.8	12.7	28.5
70.0	50.9	82.3	60.9	67.1	79.0	34.4	50.9	62.0
70.2	13.0	18.3	19.0	27.5	33.5	17.0		22.2
70.3								
70T	39.2	56.7	57.2	61.8	60.8	32.9	37.0	51.8
83.1	24.4	50.2	42.0	50.9	54.5	26.5	26.1	42.2
85.0	5.7	11.9	11.5	10.2	15.5	5.0		11.2
86.6	16.6	61.6	28.5	29.2	48.3	24.7	17.4	35.4
91.0	19.7	27.0	18.4	25.7	30.0	16.0	7.9	21.3
Mean	26.3	51.7	39.3	50.4	46.7	25.2	22.5	40.0

Central North Bus	WEEKDAY BOARDINGS PER VEHICLE TRIP	CTPS
Technical Memorandum KHQ 1-28-87		TABLE 3

Route	Early	AM Peak	Mid-day	School	PM Peak	Evening	Night	All Day
1.0	5.6	11.9	10.5	14.0	12.0	5.2	5.5	9.8
1.1							4.6	4.6
1T	5.6	11.9	10.5	14.0	12.0	5.2	5.4	9.7
47.0	6.8	13.8	12.4	13.2	11.2	5.6	6.1	10.3
47.4	6.9	10.9	12.9	14.7	11.1	9.5		11.5
47T	6.8	12.1	12.4	13.7	11.2	5.9	6.1	10.6
57.0	7.4	11.4	6.4	8.5	7.6	5.1	4.1	7.2
60.0	4.4	7.6	4.2	6.5	8.7	3.2	1.5	4.1
60.1		6.6	1.1	6.5	6.3			6.2
60.2						0.8		0.8
60.3								
60.4		11.7			7.9			8.1
60T	3.8	9.3	4.1	6.5	7.4	3.0	1.4	4.8
63.0	3.4	9.6	6.1	7.5	9.0	3.7		6.9
63.1						8.8	2.2	2.7
63T	3.4	9.6	6.1	7.5	9.0	4.6	2.2	6.2
64.5	5.0	8.0	3.4	5.4	6.1	3.4		5.1
65.0	5.6	9.2	6.6	10.4	8.9	4.5		8.0
66.0	6.3	17.0	13.4	16.1	12.6	9.2	4.9	12.4
69.0	9.6	18.9	11.5	14.6	14.8	5.2	5.2	11.6
70.0	5.3	8.6	6.4	7.0	8.3	3.6	5.3	6.5
70.2	3.0	4.2	4.4	6.4	7.8	4.0		5.2
70.3								
70T	4.9	7.6	6.3	7.0	8.1	3.6	4.3	6.2
83.1	7.1	14.7	12.2	14.9	15.9	7.7	7.6	12.3
85.0	2.4	4.9	4.8	4.2	6.5	2.1		4.7
86.6	3.6	13.4	6.2	6.4	10.5	5.4	3.8	7.7
91.0	7.7	10.6	7.2	10.1	11.8	6.3	3.1	8.3
Mean	5.6	11.7	8.4	10.9	10.2	5.1	4.5	8.6

Central North Bus	WEEKDAY BOARDINGS PER VEHICLE REVENUE MILE	CTPS
Technical Memorandum KHQ 1-28-87		TABLE 4

Route	Early	AM Peak	Mid-Day	School	PM Peak	Evening	Night	Day
1.0	51.9	101.9	88.9	111.2	96.0	44.3	52.0	83.7
1.1							50.4	50.4
1T	51.9	101.9	88.9	111.2	96.0	44.3	51.9	83.2
47.0	64.9	106.8	96.4	90.8	77.5	58.3	63.1	84.4
47.4	51.2	82.4	101.3	103.0	78.0	66.7		84.0
47T	61.4	93.0	96.6	94.9	77.7	59.1	63.1	84.3
57.0	80.8	113.9	66.9	77.5	69.1	46.2	45.2	71.1
60.0	52.4	77.0	39.0	56.6	88.0	32.9	18.9	41.4
60.1		49.0	7.5	43.2	42.4			43.4
60.2						10.0		10.0
60.3								
60.4		76.0			57.5			66.2
60T	46.3	67.1	38.0	55.7	53.8	30.6	18.1	45.9
63.0	37.3	86.0	54.5	66.8	80.3	28.6		61.8
63.1						96.0	25.7	32.1
63T	37.3	86.0	54.5	66.8	80.3	37.0	25.7	57.8
64.5	58.5	69.7	29.3	46.7	53.2	29.8		45.2
65.0	46.0	75.2	49.8	74.0	58.1	28.9		58.8
66.0	63.8	131.6	86.8	118.5	49.7	65.7	38.0	80.8
69.0	86.3	92.8	84.9	86.1	96.8	37.6	43.5	83.3
70.0	84.8	164.5	60.9	64.6	79.0	36.0	50.9	66.2
70.2	34.7	36.5	42.2	61.1	67.0	34.0		46.8
70.3								
70T	73.9	113.3	60.1	64.4	76.0	35.9	43.3	63.0
83.1	90.4	100.4	83.9	101.9	109.0	60.2	69.5	91.7
85.0	28.3	23.8	33.9	30.5	46.5	14.3		35.6
86.6	42.6	123.1	37.9	43.8	77.3	44.4	34.8	56.7
91.0	61.8	54.0	53.9	68.5	80.4	44.8	31.6	62.0
Mean	61.0	97.7	69.5	85.7	74.6	44.2	45.3	72.2

Central North Bus

Technical Memorandum
KHQ 1-28-87

WEEKDAY BOARDINGS PER
VEHICLE REVENUE HOUR

CTPS
TABLE
5

Route	Direction	Period	No. of Bus-trips	Average Max Load	# Trips w/ Standees	% Trips w/ Standees	Total Standees	Average Standees	Standees/ Passengers
1.0	out	early	11	26	0	0.00	0	0	0.00
1.0	out	AM peak	20	45	11	0.55	86	4	0.06
1.0	out	midday	37	33	7	0.19	74	2	0.03
1.0	out	school	17	42	6	0.35	64	4	0.05
1.0	out	PM peak	20	37	5	0.25	82	4	0.06
1.0	out	evening	12	27	1	0.08	6	1	0.01
1.0	out	night	18	18	0	0.00	0	0	0.00
1.0	in	early	6	16	0	0.00	0	0	0.00
1.0	in	AM peak	19	45	7	0.37	129	7	0.10
1.0	in	midday	37	36	8	0.22	126	3	0.06
1.0	in	school	16	46	9	0.56	128	8	0.09
1.0	in	PM peak	20	41	9	0.45	118	6	0.08
1.0	in	evening	14	15	0	0.00	0	0	0.00
1.0	in	night	18	20	0	0.00	0	0	0.00
1.1	out	night	2	17	0	0.00	0	0	0.00
1.1	in	night	2	23	0	0.00	0	0	0.00
47.0	out	early	5	30	0	0.00	0	0	0.00
47.0	out	AM peak	6	50	4	0.67	40	7	0.10
47.0	out	midday	15	39	4	0.27	49	3	0.06
47.0	out	school	6	47	3	0.50	17	3	0.03
47.0	out	PM peak	7	36	1	0.14	20	3	0.05
47.0	out	evening	4	15	0	0.00	0	0	0.00
47.0	out	night	10	16	0	0.00	0	0	0.00
47.0	in	early	4	24	0	0.00	0	0	0.00
47.0	in	AM peak	6	44	2	0.33	19	3	0.04
47.0	in	midday	15	36	3	0.20	54	4	0.05
47.0	in	school	7	34	1	0.14	2	0	0.00
47.0	in	PM peak	7	29	1	0.14	1	0	0.00
47.0	in	evening	4	22	0	0.00	0	0	0.00
47.0	in	night	10	22	0	0.00	0	0	0.00
47.4	out	early	3	22	0	0.00	0	0	0.00
47.4	out	AM peak	12	49	6	0.50	111	9	0.17
47.4	out	midday	3	23	0	0.00	0	0	0.00
47.4	out	school	5	20	0	0.00	0	0	0.00
47.4	out	PM peak	7	9	0	0.00	0	0	0.00
47.4	in	early	1	7	0	0.00	0	0	0.00
47.4	in	AM peak	12	14	0	0.00	0	0	0.00
47.4	in	school	7	48	4	0.57	70	10	0.19
47.4	in	PM peak	6	42	3	0.50	46	8	0.15
57.0	out	early	3	40	0	0.00	0	0	0.00
57.0	out	AM peak	19	34	5	0.26	57	3	0.07
57.0	out	midday	35	20	1	0.03	11	0	0.01
57.0	out	school	18	37	4	0.22	32	2	0.03
57.0	out	PM peak	19	41	8	0.42	88	5	0.09
57.0	out	evening	14	29	1	0.07	21	2	0.04
57.0	out	night	18	28	2	0.11	24	1	0.04
57.0	in	early	8	34	0	0.00	0	0	0.00
57.0	in	AM peak	19	60	13	0.68	239	13	0.17
57.0	in	midday	38	31	5	0.13	60	2	0.04

Central North Bus

Technical Memorandum
KHQ 1-28-87

WEEKDAY MAXIMUM LOADS

CTPS
TABLE
6a

Route	Direction	Period	No. of Bus-trips	Average # Max Load	Trips w/ Standees	% Trips w/ Standees	Total Standees	Average Standees	Standees/ Passengers
57.0	in	school	17	25	0	0.00	0	0	0.00
57.0	in	PM peak	18	21	0	0.00	0	0	0.00
57.0	in	evening	12	15	0	0.00	0	0	0.00
57.0	in	night	17	10	0	0.00	0	0	0.00
60.0	out	early	4	15	0	0.00	0	0	0.00
60.0	out	AM peak	1	20	0	0.00	0	0	0.00
60.0	out	midday	11	16	0	0.00	0	0	0.00
60.0	out	school	5	21	0	0.00	0	0	0.00
60.0	out	PM peak	1	28	0	0.00	0	0	0.00
60.0	out	evening	5	14	0	0.00	0	0	0.00
60.0	out	night	7	6	0	0.00	0	0	0.00
60.0	in	early	5	24	0	0.00	0	0	0.00
60.0	in	AM peak	1	35	0	0.00	0	0	0.00
60.0	in	midday	11	14	0	0.00	0	0	0.00
60.0	in	school	5	23	0	0.00	0	0	0.00
60.0	in	PM peak	0		0		0		
60.0	in	evening	4	10	0	0.00	0	0	0.00
60.0	in	night	6	9	0	0.00	0	0	0.00
60.1	out	AM peak	4	13	0	0.00	0	0	0.00
60.1	out	school	1	12	0	0.00	0	0	0.00
60.1	out	PM peak	4	13	0	0.00	0	0	0.00
60.1	in	AM peak	4	17	0	0.00	0	0	0.00
60.1	in	midday	1	4	0	0.00	0	0	0.00
60.1	in	PM peak	4	16	0	0.00	0	0	0.00
60.4	out	AM peak	5	26	1	0.20	5	1	0.03
60.4	out	PM peak	4	25	0	0.00	0	0	0.00
60.4	in	AM peak	5	29	0	0.00	0	0	0.00
60.4	in	PM peak	5	30	0	0.00	0	0	0.00
63.0	out	early	5	9	0	0.00	0	0	0.00
63.0	out	AM peak	6	26	0	0.00	0	0	0.00
63.0	out	midday	11	14	0	0.00	0	0	0.00
63.0	out	school	5	14	0	0.00	0	0	0.00
63.0	out	PM peak	6	32	0	0.00	0	0	0.00
63.0	out	evening	3	15	0	0.00	0	0	0.00
63.0	in	early	3	20	0	0.00	0	0	0.00
63.0	in	AM peak	6	35	0	0.00	0	0	0.00
63.0	in	midday	12	19	0	0.00	0	0	0.00
63.0	in	school	5	31	1	0.20	8	2	0.04
63.0	in	PM peak	6	24	0	0.00	0	0	0.00
63.0	in	evening	4	7	0	0.00	0	0	0.00
63.1	out	evening	1	40	0	0.00	0	0	0.00
63.1	out	night	5	14	0	0.00	0	0	0.00
63.1	in	night	6	7	0	0.00	0	0	0.00
64.5	out	early	3	20	0	0.00	0	0	0.00
64.5	out	AM peak	6	19	0	0.00	0	0	0.00
64.5	out	midday	11	10	0	0.00	0	0	0.00
64.5	out	school	5	22	0	0.00	0	0	0.00

Central North Bus

Technical Memorandum
KHQ 1-28-87

WEEKDAY MAXIMUM LOADS

CTPS

TABLE
6b

Route	Direction	Period	No. of Bus-trips	Average Max Load	# Trips w/ Standees	% Trips w/ Standees	Total Standees	Average Standees	Standees/ Passengers
64.5	out	PM peak	6	32	1	0.17	20	3	0.09
64.5	out	evening	3	20	0	0.00	0	0	0.00
64.5	in	early	4	18	0	0.00	0	0	0.00
64.5	in	AM peak	6	35	1	0.17	8	1	0.03
64.5	in	midday	11	15	0	0.00	0	0	0.00
64.5	in	school	4	14	0	0.00	0	0	0.00
64.5	in	PM peak	6	13	0	0.00	0	0	0.00
64.5	in	evening	5	7	0	0.00	0	0	0.00
65.0	out	early	1	15	0	0.00	0	0	0.00
65.0	out	AM peak	6	14	0	0.00	0	0	0.00
65.0	out	midday	11	14	0	0.00	0	0	0.00
65.0	out	school	5	31	1	0.20	3	1	0.01
65.0	out	PM peak	5	37	0	0.00	0	0	0.00
65.0	out	evening	2	14	0	0.00	0	0	0.00
65.0	in	AM peak	7	42	2	0.29	4	1	0.01
65.0	in	midday	12	18	0	0.00	0	0	0.00
65.0	in	school	4	28	1	0.25	4	1	0.03
65.0	in	PM peak	5	16	0	0.00	0	0	0.00
65.0	in	evening	1	10	0	0.00	0	0	0.00
66.0	out	early	9	27	1	0.11	11	1	0.03
66.0	out	AM peak	16	52	9	0.56	149	9	0.13
66.0	out	midday	26	31	3	0.12	32	1	0.02
66.0	out	school	12	33	2	0.17	14	1	0.02
66.0	out	PM peak	13	28	0	0.00	0	0	0.00
66.0	out	evening	7	19	0	0.00	0	0	0.00
66.0	out	night	11	11	0	0.00	0	0	0.00
66.0	in	early	8	11	0	0.00	0	0	0.00
66.0	in	AM peak	16	37	5	0.31	63	4	0.07
66.0	in	midday	27	31	5	0.19	30	1	0.02
66.0	in	school	13	43	4	0.31	42	3	0.04
66.0	in	PM peak	13	34	2	0.15	27	2	0.04
66.0	in	evening	6	30	1	0.17	11	2	0.04
66.0	in	night	10	16	0	0.00	0	0	0.00
69.0	out	early	3	24	0	0.00	0	0	0.00
69.0	out	AM peak	8	52	5	0.63	90	11	0.19
69.0	out	midday	16	19	0	0.00	0	0	0.00
69.0	out	school	10	19	0	0.00	0	0	0.00
69.0	out	PM peak	8	29	1	0.13	16	2	0.05
69.0	out	evening	5	12	0	0.00	0	0	0.00
69.0	out	night	11	7	0	0.00	0	0	0.00
69.0	in	early	4	17	0	0.00	0	0	0.00
69.0	in	AM peak	6	30	0	0.00	0	0	0.00
69.0	in	midday	15	22	0	0.00	0	0	0.00
69.0	in	school	9	33	2	0.22	16	2	0.04
69.0	in	PM peak	8	30	0	0.00	0	0	0.00
69.0	in	evening	4	15	0	0.00	0	0	0.00
69.0	in	night	12	10	0	0.00	0	0	0.00
70.0	out	early	6	39	3	0.50	18	3	0.06
70.0	out	AM peak	6	51	5	0.83	34	6	0.08

Central North Bus

Technical Memorandum
KHQ 1-28-87

WEEKDAY MAXIMUM LOADS

CTPS

TABLE
6c

Route	Direction	Period	No. of Bus-trips	Average Max Load	# Trips w/ Standees	% Trips w/ Standees	Total Standees	Average Standees	Standees/ Passengers
70.0	out	midday	10	43	3	0.30	21	2	0.03
70.0	out	school	7	38	2	0.29	29	4	0.06
70.0	out	PM peak	6	57	5	0.83	95	16	0.17
70.0	out	evening	4	33	0	0.00	0	0	0.00
70.0	out	night	4	36	1	0.25	2	1	0.01
70.0	in	early	3	31	0	0.00	0	0	0.00
70.0	in	AM peak	6	56	4	0.67	84	14	0.15
70.0	in	midday	11	28	0	0.00	0	0	0.00
70.0	in	school	6	40	2	0.33	16	3	0.04
70.0	in	PM peak	6	41	1	0.17	34	6	0.09
70.0	in	evening	7	22	0	0.00	0	0	0.00
70.0	in	night	4	39	2	0.50	34	9	0.18
70.2	out	early	2	15	0	0.00	0	0	0.00
70.2	out	AM peak	4	20	0	0.00	0	0	0.00
70.2	out	midday	1	13	0	0.00	0	0	0.00
70.2	out	school	1	36	0	0.00	0	0	0.00
70.2	out	PM peak	4	30	1	0.25	8	2	0.05
70.2	out	night	1	0	0	0.00	0	0	
70.2	in	early	2	9	0	0.00	0	0	0.00
70.2	in	AM peak	4	11	0	0.00	0	0	0.00
70.2	in	midday	1	19	0	0.00	0	0	0.00
70.2	in	school	1	12	0	0.00	0	0	0.00
70.2	in	PM peak	4	23	0	0.00	0	0	0.00
70.2	in	evening	1	16	0	0.00	0	0	0.00
83.1	out	early	4	12	0	0.00	0	0	0.00
83.1	out	AM peak	8	29	0	0.00	0	0	0.00
83.1	out	midday	10	36	4	0.40	16	2	0.04
83.1	out	school	8	46	4	0.50	35	4	0.07
83.1	out	PM peak	10	52	8	0.80	65	7	0.10
83.1	out	evening	4	37	1	0.25	9	2	0.05
83.1	out	night	6	30	0	0.00	0	0	0.00
83.1	in	early	6	24	0	0.00	0	0	0.00
83.1	in	AM peak	11	47	4	0.36	57	5	0.08
83.1	in	midday	12	32	0	0.00	0	0	0.00
83.1	in	school	7	31	1	0.14	27	4	0.10
83.1	in	PM peak	9	26	0	0.00	0	0	0.00
83.1	in	evening	4	18	0	0.00	0	0	0.00
83.1	in	night	5	13	0	0.00	0	0	0.00
85.0	out	early	1	4	0	0.00	0	0	0.00
85.0	out	AM peak	4	6	0	0.00	0	0	0.00
85.0	out	midday	8	13	0	0.00	0	0	0.00
85.0	out	school	3	7	0	0.00	0	0	0.00
85.0	out	PM peak	3	25	0	0.00	0	0	0.00
85.0	out	evening	1	10	0	0.00	0	0	0.00
85.0	in	early	2	6	0	0.00	0	0	
85.0	in	AM peak	4	8	0	0.00	0	0	0.00
85.0	in	midday	7	7	0	0.00	0	0	0.00
85.0	in	school	3	7	0	0.00	0	0	0.00
85.0	in	PM peak	3	4	0	0.00	0	0	0.00
85.0	in	evening	1	0	0	0.00	0	0	

Central North Bus

Technical Memorandum
KHQ 1-28-87

WEEKDAY MAXIMUM LOADS

CTPS
TABLE
6d

Route	Direction	Period	No. of Bus-trips	Average Max Load	# Trips w/ Standees	% Trips w/ Standees	Total Standees	Average Standees	Standees/ Passengers
86.6	out	early	3	11	0	0.00	0	0	0.00
86.6	out	AM peak	8	46	3	0.38	36	5	0.07
86.6	out	midday	11	23	0	0.00	0	0	0.00
86.6	out	school	5	20	0	0.00	0	0	0.00
86.6	out	PM peak	8	23	0	0.00	0	0	0.00
86.6	out	evening	5	13	0	0.00	0	0	0.00
86.6	out	night	5	13	0	0.00	0	0	0.00
86.6	in	early	5	13	0	0.00	0	0	0.00
86.6	in	AM peak	8	39	3	0.38	12	2	0.02
86.6	in	midday	11	16	0	0.00	0	0	0.00
86.6	in	school	7	15	0	0.00	0	0	0.00
86.6	in	PM peak	8	36	1	0.13	2	0	0.00
86.6	in	evening	2	27	0	0.00	0	0	0.00
86.6	in	night	5	13	0	0.00	0	0	0.00
91.0	out	early	3	20	0	0.00	0	0	0.00
91.0	out	AM peak	8	17	0	0.00	0	0	0.00
91.0	out	midday	19	12	0	0.00	0	0	0 00
91.0	out	school	8	23	0	0.00	0	0	0.00
91.0	out	PM peak	8	31	0	0.00	0	0	0.00
91.0	out	evening	4	17	0	0.00	0	0	0.00
91.0	out	night	5	10	0	0.00	0	0	0.00
91.0	in	early	4	17	0	0.00	0	0	0.00
91.0	in	AM peak	8	28	0	0.00	0	0	0.00
91.0	in	midday	20	16	0	0.00	0	0	0.00
91.0	in	school	8	16	0	0.00	0	0	0.00
91.0	in	PM peak	7	18	0	0.00	0	0	0.00
91.0	in	evening	3	10	0	0.00	0	0	0.00
91.0	in	night	5	4	0	0.00	0	0	0.00

Central North Bus

Technical Memorandum
KHQ 1-28-87

WEEKDAY MAXIMUM LOADS

CTPS

TABLE
6e

PEAK PERIODS

Route	Period	Max Load Period Ave.	Max Load Peak 1/2 Hr.	Peak Direction	Peak 1/2 Hour	Standees @ Peak Load Point Entire Period: Total Standees	Standees @ Peak Load Point Entire Period: Standees/ Boardings
70.0	AM peak	56*	74*	in	7:05-7:35	118	0.12
47.4	school	73*	73*	in	3:39-4:09	70	0.13
47.4	AM peak	49	70*	out	7:05-7:35	112	0.13
57.0	AM peak	60*	69*	in	8:02-8:32	296	0.13
70.0	PM peak	57*	69*	out	4:45-5:15	130	0.14
66.0	AM peak	52	67*	out	7:18-7:48	212	0.10
69.0	AM peak	52	66*	out	7:40-8:10	90	0.13
47.0	AM peak	50	65*	out	7:00-7:30	60	0.07
83.1	AM peak	47	64*	in	7:14-7:44	58	0.06
1.0	AM peak	45	60	in	8:01-8:31	216	0.08
47.4	PM peak	42	60	in	4:15-4:45	46	0.15
1.0	PM peak	37	59	out	4:31-5:01	200	0.07
86.6	AM peak	46	59	out	8:20-8:50	48	0.05
83.1	school	46	55	out	2:45-3:15	62	0.08
1.0	school	46	54	in	3:20-3:50	192	0.07
83.1	PM peak	52	54	out	4:00-4:30	66	0.07
70.0	school	40	54	in	2:45-3:15	46	0.05
57.0	PM peak	41	52	out	4:54-5:24	88	0.06
57.0	school	37	50	out	3:04-3:34	32	0.02
66.0	school	43	49	in	3:10-3:40	56	0.03

MIDDAY PERIOD

Route	Period	Max Load Period Ave.	Max Load Peak Hr.	Peak Direction	Peak Hour	Standees @ Peak Load Point Entire Period: Total Standees	Standees @ Peak Load Point Entire Period: Standees/ Boardings
47.0	midday	39	57	out	9:00-9:59	103	0.05
1.0	midday	36	56	in	9:13-10:12	200	0.04
57.0	midday	31	43	in	9:20-10:19	71	0.03
66.0	midday	31	44	in	12:00-12:59	62	0.02

* Exceeds MBTA standard (assuming average seated capacity of 46).

	Description	Daily Round Trips	Daily Ridership	Weekday Cost	Weekday Revenue	Net Cost (Cost-Rev)	Average Fare	Revenue to Cost Ratio	Net Cost Per Trip	Net Cost Per Pass.
Route 1	Harvard - Dudley	135.5	15861	$6,955	$5,885	$1,070	$0.37	84.6%	$7.90	$0.07
Route 47	Central Sq - Dudley - BCH	81.5	7763	$3,382	$2,937	$444	$0.38	86.9%	$5.45	$0.06
Route 57	Watertown Sq - Kenmore Sq	126.5	9942	$3,211	$3,735	($524)	$0.38	116.3%	($4.15)	($0.05)
Route 60	Chestnut Hill - Kenmore Sq	59.5	2373	$1,321	$886	$435	$0.37	67.1%	$7.31	$0.18
Route 63	Cleveland Circ - Central Sq	41.5	2362	$1,373	$943	$430	$0.40	68.7%	$10.37	$0.18
Route 64	Oak Sq - Central Sq	35.0	1540	$1,173	$586	$587	$0.38	49.9%	$16.78	$0.38
Route 65	Brighton Ctr - Kenmore Sq	29.0	1899	$629	$708	($79)	$0.37	112.5%	($2.71)	($0.04)
Route 66	Union Square - Dudley	95.5	9149	$2,266	$3,450	($1,185)	$0.38	152.3%	($12.41)	($0.13)
Route 69	Harvard - Lechmere	59.5	3390	$1,621	$1,329	$291	$0.39	82.0%	$4.90	$0.09
Route 70	Cedarwood - Central Sq	57.0	5904	$3,252	$2,317	$934	$0.39	71.3%	$16.39	$0.16
Route 83	Rindge Ave - Central Sq	53.0	4468	$1,626	$1,592	$34	$0.36	97.9%	$0.64	$0.01
Route 85	Spring Hill - Kendall Sq	20.0	449	$404	$166	$239	$0.37	40.9%	$11.94	$0.53
Route 86	Union Square - Sullivan Sq	46.5	3260	$1,761	$1,194	$566	$0.37	67.8%	$12.18	$0.17
Route 91	Sullivan Sq - Central Sq	55.0	2339	$1,164	$885	$279	$0.38	76.0%	$5.08	$0.12
Total/Average		***895.0***	***70699***	***$30,137***	***$26,614***	***$3,523***	***$0.38***	***88.3%***	***$3.94***	***$0.05***

Notes:
1. Weekday costs based upon March 1986 Cost/Trip figures supplied by the MBTA, times the number of daily trips in the fall1984 schedule.
2. Revenue estimates based upon derived average fare by route and fare type using 1984 (and still current) fare levels. Fare type information from CN Bus survey, fall 1984.

Central North Bus	WEEKDAY OPERATING COSTS AND REVENUES	CTPS
Technical Memorandum KHQ 1-28-87		TABLE 8

Route	Period	Direction	% Trips On time	# Observed Trips	# Trips > 5 Minutes Late
1.0	PM peak	out	69	16	5
1.0	Evening	in	78	9	2
47.0	AM peak	out	85	7	1
47.0	Midday	out	76	17	4
47.0	School	out	89	9	1
47.0	PM peak	in	71	7	2
47.0	Evening	out	75	4	1
47.0	Night	out	89	9	1
47.4	School	out	80	5	1
47.4	PM peak	out	67	9	3
47.4	PM peak	in	57	7	3
60.0	Early	out	75	4	1
60.1	AM peak	out	67	3	1
63.0	PM peak	out	67	6	2
63.1	Night	out	80	5	1
64.5	Midday	out	88	8	1
64.5	Midday	in	89	9	1
65.0	AM peak	out	83	6	1
65.0	Midday	out	91	11	1
65.0	PM peak	out	75	4	1
65.0	PM peak	in	50	4	2
69.0	Midday	out	92	13	1
69.0	PM peak	out	67	6	2
69.0	PM peak	in	67	6	2
69.0	Evening	out	80	5	1
69.0	Evening	in	88	8	1
69.0	Night	out	82	11	2
70.0	School	out.	88	8	1
70.0	PM peak	out	83	6	1
70.0	PM peak	in	86	7	1
70.0	Evening	in	75	8	2
86.6	Midday	in	90	10	1
86.6	Night	in	75	4	1

Central North Bus

Technical Memorandum
KHQ 1-28-87

LATE SERVICE
ACCORDING TO MBTA STANDARDS

CTPS

TABLE
9

Route	Period	Direction	# Trips >= 2 Minutes Early	# Observed Trips	% Trips Early
1.0	AM peak	in	2	16	13
1.0	Midday	out	5	32	16
1.0	Midday	in	5	31	16
1.0	School	in	4	14	29
1.0	PM peak	in	4	19	21
47.0	School	in	3	9	33
57.0	AM peak	in	3	28	11
57.0	Midday	out	5	33	15
57.0	Midday	in	7	36	19
57.0	School	in	2	13	15
57.0	PM peak	in	2	20	10
60.4	PM peak	in	3	7	43
66.0	School	in	2	11	18
69.0	School	out	2	11	18
69.0	Evening	in	2	8	25
91.0	School	out	2	13	15

Central North Bus	EARLY SERVICE	CTPS
Technical Memorandum KHQ 1-28-87		TABLE 10

Route	Direction	Period	Running Time Mean	Std. Dev.	Std. Dev./ Mean	Headway
1.0	out	early	28.5	3.5	0.12	12
1.0	out	AM peak	34.6	2.8	0.08	6
1.0	out	midday	32.7	3.6	0.11	9
1.0	out	school	38.1	5.4	0.14	7
1.0	out	PM peak	41.4	4.6	0.11	6
1.0	out	evening	30.7	3.5	0.11	8
1.0	out	night	27.7	4.7	0.17	15
1.0	in	early	26.8	3.6	0.13	12
1.0	in	AM peak	36.6	5.1	0.14	6
1.0	in	midday	36.0	4.3	0.12	9
1.0	in	school	41.4	6.2	0.15	7
1.0	in	PM peak	42.9	5.7	0.13	6
1.0	in	evening	34.8	4.0	0.11	8
1.0	in	night	31.2	5.8	0.19	15
1.1	out	night	27.0	2.6	0.10	15
1.1	in	night	30.7	4.9	0.16	15
47.0	out	early	27.7	2.3	0.08	25
47.0	out	AM peak	32.0	2.7	0.08	20
47.0	out	midday	30.9	2.9	0.09	20
47.0	out	school	36.3	4.2	0.12	18
47.0	out	PM peak	38.9	6.6	0.17	18
47.0	out	evening	28.3	2.2	0.08	30
47.0	out	night	23.9	4.6	0.19	30
47.0	in	early	28.5	4.7	0.16	25
47.0	in	AM peak	39.5	8.4	0.21	20
47.0	in	midday	35.4	4.2	0.12	20
47.0	in	school	36.1	6.6	0.18	18
47.0	in	PM peak	38.3	5.1	0.13	18
47.0	in	evening	32.3	5.3	0.16	30
47.0	in	night	26.5	4.3	0.16	30
47.4	out	early	18.5	0.7	0.04	10
47.4	out	AM peak	21.8	1.6	0.07	10
47.4	out	midday	21.7	3.5	0.16	10
47.4	out	school	22.2	2.2	0.10	18
47.4	out	PM peak	26.8	5.5	0.21	18
47.4	in	AM peak	21.7	3.6	0.17	10
47.4	in	school	25.8	3.4	0.13	18
47.4	in	PM peak	25.9	8.0	0.31	18
57.0	out	early	24.0	3.4	0.14	15
57.0	out	AM peak	25.3	5.3	0.21	6
57.0	out	midday	23.1	3.3	0.14	9
57.0	out	school	26.0	2.6	0.10	8
57.0	out	PM peak	29.5	3.9	0.13	6
57.0	out	evening	26.3	3.7	0.14	8
57.0	out	night	23.9	5.4	0.23	15

Central North Bus

Technical Memorandum
KHQ 1-28-87

OBSERVED RUNNING TIMES
BY PERIOD AND DIRECTION

CTPS
TABLE
11a

Route	Direction	Period	Running Time Mean	Std. Dev.	Std. Dev./ Mean	Headway
57.0	in	early	24.2	3.3	0.14	15
57.0	in	AM peak	31.6	5.0	0.16	6
57.0	in	midday	26.1	2.9	0.11	9
57.0	in	school	25.8	3.5	0.14	8
57.0	in	PM peak	30.6	4.8	0.16	6
57.0	in	evening	24.5	2.3	0.09	8
57.0	in	night	21.5	2.8	0.13	15
60.0	out	early	19.3	0.6	0.03	25
60.0	out	AM peak	25.0	*	na	na
60.0	out	midday	23.6	3.6	0.15	28
60.0	out	school	27.8	3.3	0.12	28
60.0	out	PM peak	31.0	*	na	na
60.0	out	evening	24.2	1.6	0.07	26
60.0	out	night	15.8	2.5	0.16	50
60.0	in	early	23.0	2.8	0.12	25
60.0	in	AM peak	24.0	*	na	na
60.0	in	midday	23.8	3.0	0.13	28
60.0	in	school	26.5	3.7	0.14	28
60.0	in	evening	20.3	2.5	0.12	26
60.0	in	night	18.5	2.6	0.14	50
60.1	out	AM peak	18.0	1.0	0.06	22.5
60.1	out	school	20.0	*	na	na
60.1	out	PM peak	20.8	3.5	0.17	25
60.1	in	AM peak	26.5	10.6	0.40	22.5
60.1	in	midday	15.0	*	na	na
60.1	in	PM peak	16.0	2.6	0.16	25
60.4	out	AM peak	23.0	4.0	0.17	20
60.4	out	PM peak	26.6	2.5	0.09	25
60.4	in	AM peak	32.4	5.9	0.18	20
60.4	in	PM peak	24.6	2.6	0.11	25
63.0	out	early	16.5	2.1	0.13	20
63.0	out	AM peak	21.3	2.7	0.13	20
63.0	out	midday	21.5	2.7	0.13	30
63.0	out	school	22.0	1.4	0.06	20
63.0	out	PM peak	25.6	1.8	0.07	20
63.0	out	evening	22.7	0.6	0.03	20
63.0	in	early	17.0	*	na	25
63.0	in	AM peak	25.2	3.2	0.13	20
63.0	in	midday	22.3	1.9	0.09	30
63.0	in	school	26.5	1.3	0.05	20
63.0	in	PM peak	27.8	4.8	0.17	20
63.0	in	evening	17.0	2.2	0.13	20
63.1	out	evening	31.0	*	na	60
63.1	out	night	23.4	2.5	0.11	60

Central North Bus Technical Memorandum KHO 1-28-87	OBSERVED RUNNING TIMES BY PERIOD AND DIRECTION	CTPS TABLE 11b

Route	Direction	Period	Running Time Mean	Std. Dev.	Std. Dev./ Mean	Headway
63.1	in	night	16.7	2.3	0.14	60
64.5	out	early	16.0	*	na	22
64.5	out	AM peak	21.0	3.2	0.15	20
64.5	out	midday	22.8	1.5	0.07	30
64.5	out	school	25.2	4.0	0.16	30
64.5	out	PM peak	26.2	5.2	0.20	20
64.5	out	evening	20.5	0.7	0.03	20
64.5	in	early	17.0	*	na	22
64.5	in	AM peak	22.8	3.8	0.17	20
64.5	in	midday	18.1	2.6	0.14	30
64.5	in	school	20.5	1.0	0.05	30
64.5	in	PM peak	25.5	4.3	0.17	20
64.5	in	evening	19.0	3.4	0.18	20
65.0	out	AM peak	23.8	2.2	0.09	20
65.0	out	midday	23.1	4.7	0.20	28
65.0	out	school	28.4	3.8	0.13	28
65.0	out	PM peak	28.5	3.4	0.12	25
65.0	out	evening	28.0	*	na	15
65.0	in	AM peak	36.0	6.4	0.18	20
65.0	in	midday	28.9	4.7	0.16	28
65.0	in	school	25.7	1.2	0.05	28
65.0	in	PM peak	25.2	4.7	0.19	25
65.0	in	evening	31.0	*	na	25
66.0	out	early	16.0	1.0	0.06	14
66.0	out	AM peak	22.6	2.7	0.12	7.5
66.0	out	midday	24.4	3.2	0.13	12
66.0	out	school	27.7	3.9	0.14	10
66.0	out	PM peak	27.5	6.0	0.22	8.5
66.0	out	evening	22.3	3.9	0.17	16
66.0	out	night	22.0	4.2	0.19	30
66.0	in	early	17.5	1.9	0.11	14
66.0	in	AM peak	27.3	6.9	0.25	7.5
66.0	in	midday	31.0	5.2	0.17	12
66.0	in	school	35.0	3.4	0.10	10
66.0	in	PM peak	33.6	4.1	0.12	8.5
66.0	in	evening	22.5	3.2	0.14	16
66.0	in	night	22.0	4.2	0.19	30
69.0	out	early	12.5	2.1	0.17	32
69.0	out	AM peak	15.7	2.0	0.13	12.5
69.0	out	midday	15.5	2.9	0.19	20
69.0	out	school	15.9	2.4	0.15	12.5
69.0	out	PM peak	17.7	2.5	0.14	15
69.0	out	evening	12.8	2.4	0.19	20.5
69.0	out	night	10.4	1.7	0.16	30
69.0	in	early	9.0	1.7	0.19	27

Central North Bus

Technical Memorandum
KHQ 1-28-87

OBSERVED RUNNING TIMES
BY PERIOD AND DIRECTION

CTPS
TABLE
11c

Route	Direction	Period	Running Time Mean	Std. Dev.	Std. Dev./ Mean	Headway
69.0	in	AM peak	14.7	2.3	0.16	20
69.0	in	midday	13.3	2.3	0.17	20
69.0	in	school	16.4	3.2	0.20	12.5
69.0	in	PM peak	16.6	4.1	0.25	15
69.0	in	evening	16.9	6.3	0.37	20.5
69.0	in	night	11.7	2.7	0.23	30
70.0	out	early	35.4	5.7	0.16	20
70.0	out	AM peak	41.8	4.4	0.11	20
70.0	out	midday	47.8	4.4	0.09	30
70.0	out	school	51.7	8.0	0.15	17
70.0	out	PM peak	53.2	6.5	0.12	20
70.0	out	evening	43.0	5.0	0.12	20
70.0	out	night	39.8	3.9	0.10	60
70.0	in	early	34.0	4.2	0.12	28
70.0	in	AM peak	44.8	3.4	0.08	20
70.0	in	midday	40.8	4.3	0.11	30
70.0	in	school	44.4	6.2	0.14	18
70.0	in	PM peak	50.6	10.3	0.20	20
70.0	in	evening	36.1	2.7	0.07	20
70.0	in	night	38.3	6.1	0.16	60
70.2	out	early	18.0	*	na	25
70.2	out	AM peak	18.5	2.6	0.14	20/40
70.2	out	midday	19.0	*	na	na
70.2	out	school	21.0	*	na	na
70.2	out	PM peak	22.3	3.1	0.14	20/40
70.2	in	AM peak	18.0	0.8	0.04	20/40
70.2	in	midday	21.0	*	na	na
70.2	in	school	19.0	*	na	na
70.2	in	PM peak	20.3	1.5	0.07	20/40
70.2	in	evening	22.0	*	na	na
83.1	out	early	16.3	3.2	0.20	20
83.1	out	AM peak	19.2	2.9	0.15	10
83.1	out	midday	18.4	2.8	0.15	30
83.1	out	school	21.9	3.8	0.17	15
83.1	out	PM peak	24.8	4.6	0.19	12
83.1	out	evening	21.3	1.0	0.05	27
83.1	out	night	16.0	4.2	0.26	60
83.1	in	early	18.0	2.8	0.16	20
83.1	in	AM peak	27.8	6.0	0.22	10
83.1	in	midday	21.3	5.1	0.24	30
83.1	in	school	23.3	3.9	0.17	15
83.1	in	PM peak	23.4	2.2	0.09	12
83.1	in	evening	22.0	2.2	0.10	32
83.1	in	night	14.4	2.4	0.17	60
85.0	out	early	9.0	*	na	na

Central North Bus

Technical Memorandum
KHQ 1-28-87

OBSERVED RUNNING TIMES
BY PERIOD AND DIRECTION

CTPS
TABLE
11 d

Route	Direction	Period	Running Time Mean	Running Time Std. Dev.	Running Time Std. Dev./ Mean	Headway
85.0	out	AM peak	10.5	1.3	0.12	30
85.0	out	midday	16.3	2.3	0.14	40
85.0	out	school	12.0	**	na	40
85.0	out	PM peak	11.5	2.1	0.18	40
85.0	in	early	8.0	1.4	0.18	25
85.0	in	AM peak	13.3	2.2	0.17	33
85.0	in	midday	16.1	2.3	0.14	42
85.0	in	school	15.7	4.0	0.25	40
85.0	in	PM peak	11.0	**	na	40
85.0	in	evening	11.0	*	na	na
86.6	out	early	20.0	*	na	25
86.6	out	AM peak	27.4	4.0	0.15	15
86.6	out	midday	25.0	3.6	0.14	30
86.6	out	school	27.3	2.6	0.10	20
86.6	out	PM peak	31.4	5.4	0.17	15
86.6	out	evening	23.5	2.4	0.10	23
86.6	out	night	20.8	2.9	0.14	60
86.6	in	early	20.3	1.5	0.07	20
86.6	in	AM peak	29.6	5.1	0.17	15
86.6	in	midday	28.6	3.9	0.14	30
86.6	in	school	28.8	2.4	0.08	20
86.6	in	PM peak	32.0	2.6	0.08	15
86.6	in	evening	23.0	2.8	0.12	33
86.6	in	night	18.8	1.0	0.05	60
91.0	out	early	11.0	*	na	30
91.0	out	AM peak	14.1	2.2	0.16	15
91.0	out	midday	13.2	2.3	0.17	15/20
91.0	out	school	16.4	3.6	0.22	15
91.0	out	PM peak	17.1	3.1	0.18	15
91.0	out	evening	10.6	6.4	0.60	33
91.0	out	night	13.5	1.3	0.10	60
91.0	in	early	13.5	2.1	0.16	25
91.0	in	AM peak	17.0	2.9	0.17	15
91.0	in	midday	17.3	2.5	0.14	15/20
91.0	in	school	18.7	3.6	0.19	15
91.0	in	PM peak	16.2	3.8	0.23	15
91.0	in	evening	13.8	3.0	0.22	42
91.0	in	night	13.2	2.0	0.15	60

* Only one trip was observed in this period, so no standard deviation was calculated.

** All trips in the period had the same running time, so the standard deviation is equal to zero.

Central North Bus Technical Memorandum KHQ 1-28-87	OBSERVED RUNNING TIMES BY PERIOD AND DIRECTION	CTPS TABLE 11e

Route	Period	Late Below MBTA Std.	Early Below MBTA Std.	Scheduled Cycle Time	Scheduled Round Trip Run Time	Observed Round Trip Run Time	Cycle/Sched Round Trip Run Time	Cycle/Obsvd Round Trip Run Time	Scheduled Recovery Time	Observed Recovery Time	Required Recovery Time* Total	out	in
1.0	Early			72	64	56	1.13	1.29	8	16	10	5	5
	AM peak		in	84	72	72	1 17	1.17	12	12	11	4	7
	Midday		out/in	85	74	69	1.15	1.23	11	16	11	5	6
	School		in	91	82	79	1 11	1.15	9	12	15	7	8
	PM peak	out	in	90	82	84	1 10	1.07	8	6	13	6	7
	Evening	In		85	72	66	1.18	1.29	13	19	10	5	5
	Night			75	64	59	1.17	1.27	11	16	14	6	8
1.1	Night			75	70	58	1.07	1.29	5	17	9	3	6
47 0	Early			65	46	57	1.41	1.14	19	8	9	3	6
	AM peak	out		80	64	72	1.25	1.11	16	8	15	4	11
	Midday	out		80	64	66	1.25	1.21	16	14	9	4	5
	School	out	in	90	64	72	1.41	1.25	26	18	14	5	9
	PM peak	In		90	64	77	1.41	1.17	26	13	16	9	7
	Evening	out		60	46	60	1.30	1.00	14	0	10	3	7
	Night	out		60	46	51	1.30	1.18	14	9	12	6	6
47.4	AM peak			50	42	44	1.19	1.14	8	6	7	2	5
	School	out		54	42	48	1.29	1.13	12	6	7	3	4
	PM peak	out/in		54	42	53	1.29	1.02	12	1	17	7	10
57.0	Early			60	44	48	1.36	1.25	16	12	8	4	4
	AM peak		in	66	56	57	1.18	1.16	10	9	14	7	7
	Midday		out/in	63	51	49	1.24	1.29	12	14	8	4	4
	School		in	72	57	52	1.26	1.38	15	20	8	3	5
	PM peak		in	72	59	61	1.22	1.18	13	11	11	5	6
	Evening			72	51	51	1.41	1.41	21	21	8	5	3
	Night			60	44	46	1.36	1.30	16	14	11	7	4
60.0	Early	out		50	40	42	1.25	1.19	10	8	5	1	4
	Midday			65	53	48	1.23	1.35	12	17	9	5	4
	School			70	56	55	1.25	1.27	14	15	9	4	5
	Evening			60	46	44	1.30	1.36	14	16	5	2	3
	Night			50	43	35	1.16	1.43	7	15	6	3	3

Central North Bus

Technical Memorandum
KHQ 1-28-87

ON-TIME PERFORMANCE AND TIME-RELATED MEASURES

CTPS

TABLE
12a

Route	Period	Late Below MBTA Std.	Early Below MBTA Std.	Scheduled Cycle Time	Scheduled Round Trip Run Time	Observed Round Trip Run Time	Cycle/Sched Round Trip Run Time	Cycle/Obsvd Round Trip Run Time	Scheduled Recovery Time	Observed Recovery Time	Required Recovery Time* Total	out	in
60.1	AM peak	out		45	35	45	1.29	1.00	10	0	15	1	14
	PM peak			50	41	37	1.22	1.35	9	13	8	5	3
60.4	AM peak			60	51	55	1.18	1.09	9	5	13	5	8
	PM peak		in	75	58	52	1.29	1.44	17	23	6	3	3
63.0	Early			40	35	34	1.14	1.18	5	6	na	3	**
	AM peak			60	48	46	1.25	1.30	12	14	8	4	4
	Midday			60	41	44	1.46	1.36	19	16	6	4	2
	School			60	54	49	1.11	1.22	6	11	4	2	2
	PM peak	out		60	54	54	1.11	1.11	6	6	8	2	6
	Evening			50	35	40	1.43	1.25	15	10	4	1	3
63.1	Night	out		55	47	40	1.17	1.38	8	15	6	3	3
64.5	Early			44	37	33	1.19	1.33	7	11	na	***	**
	AM peak			60	47	44	1.28	1.36	13	16	9	4	5
	Midday	out/in		60	42	41	1.43	1.46	18	19	5	2	3
	School			60	42	46	1.43	1.30	18	14	6	5	1
	PM peak			60	53	52	1.13	1.15	7	8	13	7	6
	Evening			60	37	40	1.62	1.50	23	20	5	1	4
65.0	AM peak	out		60	50	60	1.20	1.00	10	0	11	3	8
	Midday	out		56	45	52	1.24	1.08	11	4	12	6	6
	School			56	51	54	1.10	1.04	5	2	7	5	2
	PM peak	out/in		75	60	54	1.25	1.39	15	21	10	4	6
	Evening			75	49	59	1.53	1.27	26	16	na	**	**
66.0	Early			46	34	34	1.35	1.35	12	12	3	1	2
	AM peak			60	47	50	1.28	1.20	13	10	13	4	9
	Midday			72	50	55	1.44	1.31	22	17	11	4	7
	School		in	63	58	63	1.09	1.00	5	0	9	5	4
	PM peak			68	58	62	1.17	1.10	10	6	13	8	5
	Evening			65	46	45	1.41	1.44	19	20	9	5	4
	Night			60	34	40	1.76	1.50	26	20	10	5	5

Central North Bus

Technical Memorandum
KHQ 1-28-87

ON-TIME PERFORMANCE AND TIME-RELATED MEASURES

CTPS

TABLE
12b

Route	Period	Late Below MBTA Std.	Early Below MBTA Std.	Scheduled Cycle Time	Scheduled Round Trip Run Time	Observed Round Trip Run Time	Cycle/Sched Round Trip Run Time	Cycle/Obsvd Round Trip Run Time	Scheduled Recovery Time	Observed Recovery Time	Required Recovery Time* total	out	in
69.0	Early			32	24	22	1.33	1.45	8	10	5	3	2
	AM peak			40	31	31	1.29	1.29	9	9	6	3	3
	Midday	out		40	29	29	1.38	1.38	11	11	7	4	3
	School		out	50	29	32	1.72	1.56	21	18	7	3	4
	PM peak	out/in		45	36	35	1.25	1.29	9	10	8	3	5
	Evening	out/in	in	41	26	30	1.58	1.37	15	11	11	3	8
	Night	out		30	24	22	1.25	1.36	6	8	6	2	4
70.0	Early			72	68	69	1.06	1.04	4	3	12	7	5
	AM peak			100	93	87	1.08	1.15	7	13	10	6	4
	Midday			120	83	89	1.45	1.35	37	31	12	6	6
	School	out		125	83	96	1.51	1.30	42	29	18	10	8
	PM peak	out/in		120	92	104	1.30	1.15	28	16	21	8	13
	Evening	in		105	68	79	1.54	1.33	37	26	11	7	4
	Night			75	68	78	1.10	0.96	7	-3	13	5	8
70.2	AM peak			60	46	37	1.30	1.62	14	23	4	3	1
	Midday			55	37	40	1.49	1.38	18	15	na	**	**
	School			55	37	40	1.49	1.38	18	15	na	**	**
	PM peak			60	46	42	1.30	1.43	14	18	6	4	2
83.1	Early			40	37	34	1.08	1.18	3	6	8	4	4
	AM peak			60	50	47	1.20	1.28	10	13	12	4	8
	Midday			60	46	39	1.30	1.54	14	21	11	4	7
	School			60	46	45	1.30	1.33	14	15	10	5	5
	PM peak			60	58	48	1.03	1.25	2	12	9	6	3
	Evening			53	37	43	1.43	1.23	16	10	4	1	3
	Night			45	37	30	1.22	1.50	8	15	8	5	3
85.0	Early			25	20	17	1.25	1.47	5	8	na	**	2
	AM peak			33	25	24	1.32	1.38	8	9	5	2	3
	Midday			41	24	32	1.71	1.28	17	9	6	3	3
	School			40	24	28	1.67	1.43	16	12	na	***	5
	PM peak			40	26	23	1.54	1.74	14	17	na	3	***
86.6	Early			52	39	40	1.33	1.30	13	12	na	**	2

Central North Bus

Technical Memorandum
KHQ 1-28-87

ON-TIME PERFORMANCE AND TIME-RELATED MEASURES

CTPS

TABLE
12c

Route	Period	Late Below MBTA Std.	Early Below MBTA Std.	Scheduled Cycle Time	Scheduled Round Trip Run Time	Observed Round Trip Run Time	Cycle/Sched Round Trip Run Time	Cycle/Obsvd Round Trip Run Time	Scheduled Recovery Time	Observed Recovery Time	Required Recovery Time* Total	out	in
86.6	AM peak			75	64	57	1.17	1.32	11	18	12	5	7
	Midday	In		90	59	54	1.53	1.67	31	36	10	5	5
	School			80	59	56	1.36	1.43	21	24	6	3	3
	PM peak			75	64	63	1.17	1.19	11	12	11	7	4
	Evening			66	49	49	1.35	1.35	17	17	7	3	4
	Night	In		60	39	40	1.54	1.50	21	20	5	4	1
91.0	Early			30	25	23	1.20	1.30	5	7	na	**	3
	AM peak			45	33	31	1.36	1.45	12	14	7	3	4
	Midday			41	27	30	1.52	1.37	14	11	6	3	3
	School		out	45	31	35	1.45	1.29	14	10	10	5	5
	PM peak			45	36	33	1.25	1.36	9	12	9	4	5
	Evening			43	27	25	1.59	1.72	16	18	12	8	4
	Night			30	25	27	1.20	1.11	5	3	5	2	3

* Required recovery time calculated as follows: (1.3 X std. dev. of outbound observed running time) + (1.3 X std. dev. of inbound observed running time)
This ensures that 90% of trips will depart terminals according to scheduled times. Out = after outbound trips.

** Only one trip was observed, so no measure of variability, hence required recovery time, could be calculated.

*** All trips had the same running time, so no measure of variability, hence required recovery time, could be calculated.

Central North Bus	ON-TIME PERFORMANCE AND TIME-RELATED MEASURES	CTPS
Technical Memorandum KHQ 1-28-87		TABLE 12d

Route	Period	Late Below MBTA Std.	Early Below MBTA Std.	Scheduled Cycle Time	Scheduled Round Trip Run Time	Observed Round Trip Run Time	Cycle/Sched Round Trip Run Time	Cycle/Obsvd Round Trip Run Time	Scheduled Recovery Time	Observed Recovery Time	Required Recovery Time* Total	out	in
57.0	School		in	72	57	52	1.26	1.38	15	20	8	3	5
	Evening			72	51	51	1.41	1.41	21	21	8	5	3
60.0	Midday			65	53	48	1.23	1.35	12	17	9	5	4
	Evening			60	46	44	1.30	1.36	14	16	5	2	3
	Night			50	43	35	1.16	1.43	7	15	6	3	3
60.1	PM peak			50	41	37	1.22	1.35	9	13	8	5	3
60.4	PM peak		in	75	58	52	1.29	1.44	17	23	6	3	3
63.0	Midday			60	41	44	1.46	1.36	19	16	6	4	2
63.1	Night	out		55	47	40	1.17	1.38	8	15	6	3	3
64.5	Early			44	37	33	1.19	1.33	7	11	na	...	..
	AM peak			60	47	44	1.28	1.36	13	16	9	4	5
	Midday	out/in		60	42	41	1.43	1.46	18	19	5	2	3
	Evening			60	37	40	1.62	1.50	23	20	5	1	4
65.0	PM peak	out/in		75	60	54	1.25	1.39	15	21	10	4	6
66.0	Early			46	34	34	1.35	1.35	12	12	3	1	2
	Midday			72	50	55	1.44	1.31	22	17	11	4	7
	Evening			65	46	45	1.41	1.44	19	20	9	5	4
	Night			60	34	40	1.76	1.50	26	20	10	5	5
69.0	Early			32	24	22	1.33	1.45	8	10	5	3	2
	Midday	out		40	29	29	1.38	1.38	11	11	7	4	3
	School		out	50	29	32	1.72	1.56	21	18	7	3	4
	Evening	out/in	in	41	26	30	1.58	1.37	15	11	11	3	8
	Night	out		30	24	22	1.25	1.36	6	8	6	2	4
70.0	Midday			120	83	89	1.45	1.35	37	31	12	6	6
	Evening	in		105	68	79	1.54	1.33	37	26	11	7	4

Central North Bus

Technical Memorandum
KHQ 1-28-87

SERVICE THAT EXCEEDS 1.30 CYCLE-TO-OBSERVED RUNNING TIME

CTPS

TABLE 13a

Route	Period	Late Below MBTA Std.	Early Below MBTA Std.	Scheduled Cycle Time	Scheduled Round Trip Run Time	Observed Round Trip Run Time	Cycle/Sched Round Trip Run Time	Cycle/Obsvd Round Trip Run Time	Scheduled Recovery Time	Observed Recovery Time	Required Recovery Time* Total	out	in
70.2	AM peak			60	46	37	1.30	1.62	14	23	4	3	1
	Midday			55	37	40	1.49	1.38	18	15	na	**	**
	School			55	37	40	1.49	1.38	18	15	na	**	**
	PM peak			60	46	42	1.30	1.43	14	18	6	4	2
83.1	Midday			60	46	39	1.30	1.54	14	21	11	4	7
	Night			45	37	30	1.22	1.50	8	15	8	5	3
85.0	Early			25	20	17	1.25	1.47	5	8	na	**	2
	AM peak			33	25	24	1.32	1.38	8	9	5	2	3
	School			40	24	28	1.67	1.43	16	12	na	***	5
	PM peak			40	26	23	1.54	1.74	14	17	na	3	***
86.6	AM peak			75	64	57	1.17	1.32	11	18	12	5	7
	Midday	In		90	59	54	1.53	1.67	31	36	10	5	5
	School			80	59	56	1.36	1.43	21	24	6	3	3
	Evening			66	49	49	1.35	1.35	17	17	7	3	4
	Night	In		60	39	40	1.54	1.50	21	20	5	4	1
91.0	AM peak			45	33	31	1.36	1.45	12	14	7	3	4
	Midday			41	27	30	1.52	1.37	14	11	6	3	3
	PM peak			45	36	33	1.25	1.36	9	12	9	4	5
	Evening			43	27	25	1.59	1.72	16	18	12	8	4

* Required recovery time calculated as follows: (1.3 X std. dev. of outbound observed running time) + (1.3 X std. dev. of inbound observed running time). This ensures that 90% of trips will depart terminals according to scheduled times. Out = after outbound trips.

** Only one trip was observed, so no measure of variability, hence required recovery time, could be calculated.

*** All trips had the same running time, so no measure of variability, hence required recovery time, could be calculated.

Central North Bus

Technical Memorandum
KHQ 1-28-87

SERVICE THAT EXCEEDS 1.30 CYCLE-TO-OBSERVED RUNNING TIME

CTPS

TABLE

13b

Route	Period	Late Below MBTA Std.	Early Below MBTA Std.	Scheduled Cycle Time	Scheduled Round Trip Run Time	Observed Round Trip Run Time	Cycle/Sched Round Trip Run Time	Cycle/Obsvd Round Trip Run Time	Scheduled Recovery Time	Observed Recovery Time	Required Recovery Time* Total	out	in
1.0	School		in	91	82	79	1.11	1.15	9	12	15	7	8
	PM peak	out	in	90	82	84	1.10	1.07	8	6	13	6	7
47.0	Early			65	46	57	1.41	1.14	19	8	9	3	6
	AM peak	out		80	64	72	1.25	1.11	16	8	15	4	11
	PM peak	in		90	64	77	1.41	1.17	26	13	16	9	7
	Evening	out		60	46	60	1.30	1.00	14	0	10	3	7
	Night	out		60	46	51	1.30	1.18	14	9	12	6	6
47.4	AM peak			50	42	44	1.19	1.14	8	6	7	2	5
	School	out		54	42	48	1.29	1.13	12	6	7	3	4
	PM peak	out/in		54	42	53	1.29	1.02	12	1	17	7	10
57.0	AM peak		in	66	56	57	1.18	1.16	10	9	14	7	7
60.1	AM peak	out		45	35	45	1.29	1.00	10	0	15	1	14
60.4	AM peak			60	51	55	1.18	1.09	9	5	13	5	8
63.0	PM peak	out		60	54	54	1.11	1.11	6	6	8	2	6
64.5	PM peak			60	53	52	1.13	1.15	7	8	13	7	6
65.0	AM peak	out		60	50	60	1.20	1.00	10	0	11	3	8
	Midday	out		56	45	52	1.24	1.08	11	4	12	6	6
	School			56	51	54	1.10	1.04	5	2	7	5	2
66.0	AM peak			60	47	50	1.28	1.20	13	10	13	4	9
	School		in	63	58	63	1.09	1.00	5	0	9	5	4
	PM peak			68	58	62	1.17	1.10	10	6	13	8	5
70.0	Early			72	68	69	1.06	1.04	4	3	12	7	5
	PM peak	out/in		120	92	104	1.30	1.15	28	16	21	8	13
	Night			75	68	78	1.10	0.96	7	-3	13	5	8
83.1	Early			40	37	34	1.08	1.18	3	6	8	4	4

Central North Bus

Technical Memorandum
KHQ 1-28-87

SERVICE WHOSE OBSERVED RECOVERY TIME IS LESS THAN REQUIRED

CTPS

TABLE
14a

Route	Period	Late Below MBTA Std.	Early Below MBTA Std.	Scheduled Cycle Time	Scheduled Round Trip Run Time	Observed Round Trip Run Time	Cycle/Sched Round Trip Run Time	Cycle/Obsvd Round Trip Run Time	Scheduled Recovery Time	Observed Recovery Time	Required Recovery Time* Total	out	in
91.0	Night			30	25	27	1.20	1.11	5	3	5	2	3

* Required recovery time calculated as follows: (1.3 X std. dev. of outbound observed running time) + (1.3 X std. dev. of inbound observed running time). This ensures that 90% of trips will depart terminals according to scheduled times. Out = after outbound trips.

Central North Bus	SERVICE WHOSE OBSERVED RECOVERY TIME IS LESS THAN REQUIRED	CTPS
Technical Memorandum KHQ 1-28-87		TABLE 14b

Route	early	AMPK	midday	school	PMPK	evening	night	all periods
1.0					15 x 6 ('84) 16 x 6 (rec.) (DONE)	11 x 7.7 ('84) 10 X 7.7 (rec.) 12 x 7.7 ('86)		Ensure use of correct Harv. Sq. terminal stop.
47.0		4 x 20 ('84) 5 x 18 (rec.) Alloc. 5 mins. rec. time to Cent. Sq., 13 to Dudley.			Even out trunk h.w.s			Improve BCH dispatching. Ensure correct destination signs.
47.4		5 x 10 ('84) 6 x 9 (rec.)		+1 inb. trip 3:39-3:57	3 x 18 ('84) 4 x 18 (rec.)			
57.0		11 x 6 ('84) 14 x 5 (rec.)		9 x 8 ('84) 8 x 8 (rec.)		9 x 8 ('84) 8 x 8 (rec.)		Improve Watertown Yard dispatching.
60.0			Shift 8 mins. rec. time to Rte. 65.0					
60.1								Eliminate. (DONE)
60.4		3 x 20 ('84) 4 x 15 (rec.) 4 x 17 ('86)			3 x 25 ('84) 3 x 20 (rec.) 4 x 18 ('86)			
63.0					3 x 20 ('84) 3 x 21 (rec.) Alloc. 6 mins. rec. time to Cent. Sq., 3 to Cleve. Cir.			
65.0		Shift any rec. time to Kenm. Sta.	Shift 8 mins. rec. time from Rte. 60.0		Monitor service for cause of lateness.			Update database due to elimination of 60.1.

Central North Bus	SUMMARY OF RECOMMENDED CHANGES	CTPS
Technical Memorandum KHQ 1-28-87		TABLE 15a

Route	early	AMPK	midday	school	PMPK	evening	night	all periods
66.0		8 x 8 ('84) 10 x 6 (rec.)	Shift 4 mins. rec. time from Un. to Dud. Sq	7 x 10 ('84) 8 x 10 (rec.)	8 x 8.5 ('84) 8 x 10 (rec.)			
69.0		2 x 20 ('84) +1 outbd. trip 7:40-8:10 (rec.) 3 x 15 ('86)		4 x 12.5 ('84) 3 x 12.5 (rec.)		Alloc. 8 mins. rec. time to Lech., 3 mins. to Harv.		Ensure use of correct Harv. Sq. terminal stop. Monitor route to determine cause of lateness.
70.0		5 x 20 ('84) 7 x 15 (rec.) (DONE)			6 x 20 ('84) 8 x 15 (rec.) (DONE)			
70.2								Eliminate. (DONE)
83.1								Update database due to opening of Red Line ext. to Alewife.
86.6				4 x 20 ('84) 3 x 22 (rec.) 4 x 18 ('86)	Alloc. 7 mins. rec. time to Sull. Sq., 5 to Un. Sq.		Consider operating to Brght. Cent.	
91.0		3 x 15 ('84) 2 x 20 (rec.) 2 x 25 ('86)	3 x 15 ('84) 2 x 20 (rec.) 2 x 25 ('86)	3 x 15 ('84) 2 x 20 (rec.) 2 x 25 ('86)	3 x 15 ('84) 2 x 20 (rec.) 2 x 25 ('86)			

Key: n x m = Vehicles and Headway.
('84) = Fall 1984 schedule upon which recommendations are based.
(rec.) = Recommended schedule.
('86) = Schedule as of Fall 1986, if different from recommended and Fall 1984 schedules.
(DONE) = MBTA made recommended change sometime since the Fall of 1984.

Central North Bus Technical Memorandum KHQ 1-28-87	SUMMARY OF RECOMMENDED CHANGES	CTPS TABLE 15b

APPENDIX H
MARKET ANALYSIS

CTPS

State Transportation Building
10 Park Plaza, Suite 2150
Boston, MA 02116-3968
(617) 973-7100

CENTRAL
TRANSPORTATION
PLANNING
STAFF

MEMORANDUM

TO: Central North Bus Study Files April 7, 1987

FROM: Geoff Slater

RE: Central North Bus Study - Market Analysis

This memorandum is one in a series that summarizes the results of specific tasks in the Central North Corridor Bus Study. It describes general socio-economic and travel characteristics of the corridor's residents, workers, and bus riders, and then examines possible areas of improvement for further analysis in subsequent stages of the study. The primary data sources used in this analysis were the 1980 U. S. Census, and ridership counts and surveys conducted in the Fall of 1984.

General Study Area Characteristics

For the purposes of this study, the Central North (CN) "corridor" consists of the areas shown on the map in Figure 1 in Boston, Brookline, Cambridge, Newton, Somerville, Waltham, and Watertown. In Boston, Allston/Brighton, the Back Bay, the Fenway, Parker Hill, and parts of Roxbury and the South End are included; in Newton, only the Newton Corner area is included.[1]

In 1980, the total population of this area, according to the U. S. Census, was 479,533 persons, or 8.4 percent of the state's population. The population of the area declined by almost 11 percent from 1970 to 1980, but has since begun to stabilize, declining only 0.1 percent through 1984. However, modest declines (about 0.5 percent per year) are expected to continue through 1990. While population has declined, employment has increased and is projected to continue to increase. Employment in the study area increased from 365,592 jobs in 1980 to 381,766 jobs in 1985. A gain of an additional 10,000 jobs is projected

[1]The Central North Corridor also overlaps other MBTA bus study corridors. The Cambridge and Somerville routes not included in this study were examined in the "Northwest Corridor Service Study," which was conducted by Cambridge Systematics, Inc., and completed in January 1985. In addition, the Roxbury and South End portions of Routes 1, 47 and 66, which are included in the Central North Study, were also included in the "Southwest Corridor Bus Operations Study," conducted by Tippetts-Abbett-McCarthy-Stratton (TAMS) for the MBTA.

Central North Bus Study	Central North Area Location Map	CTPS
Market Analysis		FIGURE 1

through 1990. The probable impact on transit trips attributable to these two factors will be a slight decrease in the number of trips generated from within the corridor (due to a reduction in population), and an increase in the number of transit trips going into the corridor (due to increased employment).

Most of the corridor is densely populated and well established. Population densities in the Boston, Cambridge and Somerville portion of the study area range from 12,000 per square mile (Roxbury, South End) to over 26,000 per square mile (Back Bay, Fenway). As would be expected, population densities decrease further away from Boston, dropping to 8,000 in Brookline and Watertown, and 4,000 per square mile in Waltham.

Approximately half of the study area's residents are employed, although employment and household income vary greatly within the CN corridor. For example, only 31 percent of Roxbury's residents were employed in 1980, compared to 64 percent of the Back Bay's residents. Median income ranged from a low of $5,800 per year in part of Roxbury to a high of $38,000 per year in part of Brookline. In general, median income was below $10,000 in Roxbury, Parker Hill and much of the Fenway, between $10,000 and $15,000 in most of Allston/Brighton, the South End, Cambridge and Somerville, and over $15,000 in the other areas.

The occupants of 33 percent of the area's dwelling units are without daily access to an automobile. Given an average of 2.5 residents per dwelling unit, almost 160,000 of the area's residents did not have daily access to a car and, therefore, relied on other means of transportation. The highest concentrations of households without an automobile were in the Back Bay, Fenway, Roxbury, and the South End, all of which exceeded 50 percent. However, there is a high degree of transit dependency due to lack of a car throughout the cities of Boston, Cambridge and Somerville.

Thirteen percent of the area's residents are age 65 or over. Brookline has the highest concentration of elderly residents, at 18.9 percent; the Fenway has the lowest at 5.8 percent. Although elderly persons, as a group, are traditionally considered to have a high degree of transit dependency, persons 65 or over utilize CN buses at a lower rate than do other age groups. Based upon CN survey data, as of Fall 1984, less than five percent of CN bus riders were 65 or older, and in terms of bus routes, no route carried more than 10.8 percent elderly passengers, well below the MBTA's threshold of 15 percent for application of special performance standards.

Existing Transportation Use/Patterns

According to the 1980 Census, 226,659 daily work trips were made by residents of the Central North area. The most popular

work trip destination for the area's residents was the same community or neighborhood in which they lived (26 percent), followed by Cambridge (19 percent), the Boston CBD (14 percent), the Back Bay (4 percent) and the Fenway (3 percent). Cambridge, however, unlike the others, which are fairly small in area, is much larger and contains many work-trip generators spread throughout the city. As a result, in order to better determine work trip patterns, Cambridge was divided into a number of smaller sections. This was also done with other cities and towns in the Central North area that are large in area, and resulted in the divisions listed below and as shown in the map in Figure 2.

Boston: Allston/Brighton, Back Bay, Fenway, Parker Hill, and parts of Roxbury and the South End

Brookline: North, Central and South

Cambridge: Central Square, East Cambridge, Harvard Square, North Cambridge and West Cambridge

Newton: Newton Corner (the only part of Newton in the study area)

Somerville: East, Central and West

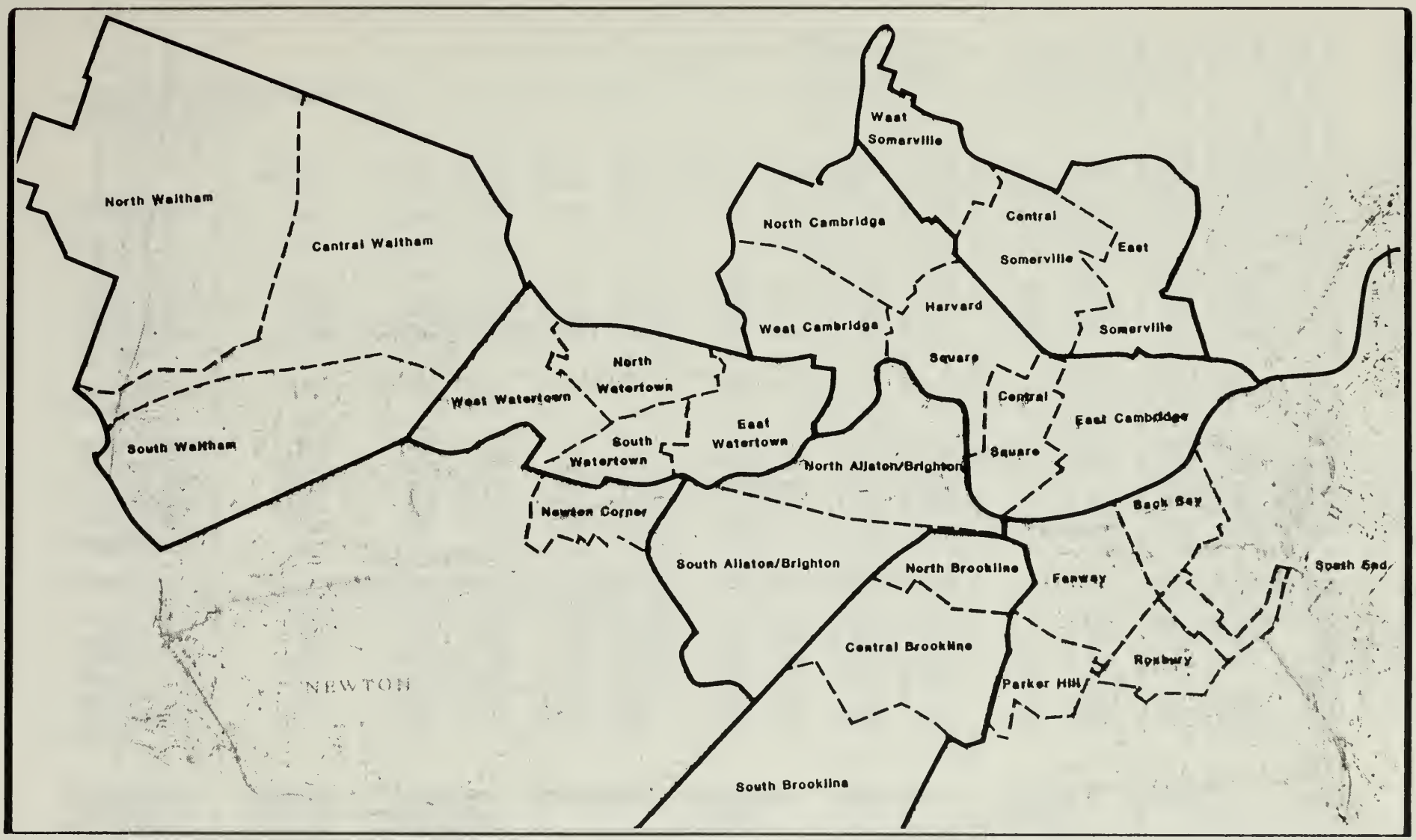
Waltham: South and Central

Watertown: North, East, South and West

On this basis, and as shown in Table 1, once trips are assigned to their respective sections of each city or town, and excluding internal trips, the Boston CBD becomes the largest work trip attractor (14 percent), followed by East Cambridge (4.7 percent), the Back Bay (4.3 percent), Harvard Square (3.9 percent), and the Fenway (3.4 percent). Although not in the table, Central Square, which is the focus of much of the CN bus service, is a work trip destination for 3.3 percent of the study area's residents. Another 29 percent of all trips were made to areas outside of the Central North area (other than the Boston CBD).

For the corridor as a whole, 37 percent of these work trips were made by private auto, 27 percent by transit, and with the remaining 36 percent split between walking, carpooling, bicycling, etc. However, as would be expected, more trips are made on transit to work locations in or closer to Boston, and fewer trips are made to work locations farther from Boston. As an example, 63 percent of all work trips to Downtown Boston from the Central North area are made on transit, while less than eight percent of all work trips to Waltham are made on transit.

Within the CN area, transit service has two major components: (1) the rail transit system, and (2) the Central North



Central North Bus Study	Central North Subarea Analysis Zones	CTPS
Market Analysis		FIGURE 2

TABLE 1
DISTRIBUTION OF WORK TRIP LOCATIONS
FOR STUDY AREA RESIDENTS*

TOWN/AREA OF RESIDENCE	EMPLOYED RESIDENTS	WORK LOCATION: HOME TOWN/ HOME AREA		BOSTON CBD		EAST CAMBRIDGE		BACK BAY		HARVARD SQUARE		FENWAY		OTHER	
BOSTON															
Allston/Brighton	34,144	4,992	14.6%	6,391	18.7%	971	2.8%	2,307	6.8%	899	2.6%	2,102	6.2%	16,482	48.3%
Back Bay	11,504	2,073	18.0%	3,324	28.9%	350	3.0%	**	**	413	3.6%	571	5.0%	4,773	41.5%
Fenway	14,907	3,523	23.6%	2,756	18.5%	458	3.1%	1,469	9.9%	160	1.1%	**	**	6,541	43.9%
Parker Hill	5,272	1,432	27.2%	894	17.0%	72	1.4%	253	4.8%	86	1.6%	443	8.4%	2,092	39.7%
Roxbury	1,900	146	7.7%	470	24.7%	0	0.0%	248	13.1%	45	2.4%	63	3.3%	928	48.8%
South End	3,602	251	7.0%	889	24.7%	224	6.2%	302	8.4%	125	3.5%	203	5.6%	1,608	44.6%
BROOKLINE	28,670	5,493	19.2%	4,539	15.8%	748	2.6%	1,724	6.0%	378	1.3%	1,916	6.7%	13,872	48.4%
CAMBRIDGE															
Central Square	12,089	1,693	14.0%	1,735	14.4%	1,642	13.6%	415	3.4%	1,508	12.5%	589	4.9%	4,507	37.3%
East Cambridge	10,977	4,019	36.6%	1,019	9.3%	**	**	391	3.6%	887	8.1%	94	0.9%	4,567	41.6%
Harvard Square	11,113	4,871	43.8%	1,198	10.8%	798	7.2%	271	2.4%	**	**	226	2.0%	3,749	33.7%
North Cambridge	9,751	1,241	12.7%	1,065	10.9%	1,140	11.7%	326	3.3%	1,207	12.4%	130	1.3%	4,642	47.6%
West Cambridge	4,236	479	11.3%	543	12.8%	257	6.1%	104	2.5%	608	14.4%	100	2.4%	2,145	50.6%
NEWTON															
Newton Corner	2,682	80	3.0%	355	13.2%	54	2.0%	136	5.1%	19	0.7%	99	3.7%	1,939	72.3%
SOMERVILLE															
East Somerville	7,466	669	9.0%	1,084	14.5%	482	6.5%	365	4.9%	226	3.0%	130	1.7%	4,510	60.4%
Central Somerville	17,678	2,432	13.8%	2,126	12.0%	1,777	10.1%	540	3.1%	1,139	6.4%	243	1.4%	9,421	53.3%
West Somerville	11,787	1,050	8.9%	1,515	12.9%	808	6.9%	239	2.0%	645	5.5%	335	2.8%	7,195	61.0%
WALTHAM	21,186	8,731	41.2%	570	2.7%	287	1.4%	209	1.0%	258	1.2%	12	0.1%	11,119	52.5%
WATERTOWN	17,695	4,431	25.0%	1,704	9.6%	578	3.3%	441	2.5%	348	2.0%	423	2.4%	9,770	55.2%
	226,659	47,606	21.0%	32,177	14.2%	10,646	4.7%	9,740	4.3%	8,951	3.9%	7,679	3.4%	109,860	48.5%

* Source: 1980 U.S. Census
** Included under " Home Town/Home Area".

and other connecting bus routes. Most of the Central North area is served by the rail transit system--the Green Line in Allston/Brighton, the Back Bay, the Fenway, Parker Hill, Brookline and East Cambridge; the Red Line in Cambridge and part of Somerville, and the Orange Line at Sullivan Square on the Somerville/Charlestown line, and in Roxbury and the South End in Boston. (Areas not served by rail transit are the northern half of Allston/Brighton, the southern half of Brookline, Newton Corner, Waltham and Watertown.) The level of rail transit service is high on all lines (in all cases higher than on CN bus routes) and service is provided to Downtown Boston as well as a large number of other locations throughout the Boston area. As a result, most transit ridership within the Central North area is on the rapid transit system.

By contrast, CN bus routes serve primarily local trips within the corridor, as well as crosstown and feeder service to rapid transit stations (all CN bus routes connect with at least one rapid transit station), and service to areas not served by rapid transit. Based on ridership counts conducted for this study, ridership on all 14 CN bus routes has been estimated at 71,200 one-way trips per day (as of fall 1984), which can be broken down by route as follows:

TABLE 2
Average Daily Ridership, by Route

Route	Daily Ridership
1	15,850
47	7,750
57	9,950
60	2,400
63	2,800
64	1,550
65	1,900
66	9,150
69	3,400
70	5,900
83	4,450
85	450
86	3,250
91	2,350
	71,200

Of these 71,200 daily trips, 50 percent were for work purposes, 17 percent for school, and six percent for shopping. Most of the trips were internal to the corridor (73 percent), and involved transfers between other buses and/or rail transit (53 percent). For riders that did transfer, transfer rates were as follows (for all CN routes combined):

TABLE 3
CN Bus Transfer Activity

# Transfers	Type	# Riders	% of Total Ridership
1	bus-bus	19,400	27.2
1	bus-rail	15,850	22.3
2 or more	all	2,300	3.2
		37,550	52.7

Although transfer rates varied significantly (see Table 4), 11 of the 14 routes had combined transfer rates (to bus and/or rapid transit) exceeding 50 percent. Routes 60, 63, 64 and 86 had the highest incidences of transfering passengers, ranging from 54 percent to 71 percent.

This high rate of transfer activity affects both ridership and productivity. Productivity, in terms of cost per rider, can be increased by requiring a high percentage of transfers because a larger area can be served with fewer buses. Ridership, on the other hand, is usually adversely affected as the inconvenience of making a transfer discourages a certain number of potential riders from taking the bus. In addition, the MBTA fare structure, which does not provide for free or discounted transfers, further discourages potential ridership by charging two fares for trips that would cost only one fare if a transfer were not involved. Therefore, increases in bus system productivity based on increases in transfer activity must be balanced against potential ridership losses.

A number of socio-economic characteristics of CN bus riders are shown in Table 4. In summary, most riders are between 18 and 34 years old (62.8 percent), with 8.9 percent under 18, and 4.6 percent over 65. Slightly over one-third of CN bus riders do not have a license, and 78 percent do not have a car available as an alternative to riding the bus. Although some presumably do not own a car by choice as a result of the amount of transit service available in the corridor, this figure does indicates a high level of transit dependency among CN bus riders.[2]

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[2]MBTA standards provide for lower performance standards for routes where more than 75 percent of all passengers do not have a car available. Fare box return requirements are reduced by 50 percent (except school service), passengers/hour from 30 to 20, and passengers/mile from 1.5 to 1.0 for off-peak periods.

TABLE 4

Socio-Economic and Travel Characteristics
(Weekdays)

	Socio-Economic Characteristics				Travel Characteristics		
	Age				% Transfers		
Route	% <18	% >64	% w/o Auto	% <15K Inc	To/From Rapid Transit	To/ From Buses	% Ride ≥5 Days/ Week
1	10.8	2.5	78.7*	37.5	5.9	36.4	69.4
47	2.2	4.2	83.7*	58.0	16.4	41.6	82.9
57	7.4	4.0	73.6	43.7	30.3	23.6	79.1
60	5.0	7.3	70.0	38.6	40.0	14.1	74.1
63	7.4	9.7	70.6	46.4	60.1	11.1	72.4
64	3.2	5.3	79.0*	43.8	47.9	13.3	81.1
65	7.2	6.5	73.8	34.4	18.7	13.0	71.2
66	11.5	5.2	83.2*	54.4	27.4	31.4	88.1
69	9.2	2.5	77.2*	41.6	31.1	32.9	67.4
70	18.4	5.6	78.9*	40.3	29.6	23.8	79.6
83	7.6	10.8	77.5*	50.2	28.9	22.2	71.6
85	1.5	4.0	73.3	36.0	21.9	13.9	84.5
86	8.5	3.3	76.4*	49.2	43.9	18.3	79.8
91	4.3	3.6	77.9*	47.2	25.5	36.6	82.9
Average	8.9	4.6	78.1*	44.9	23.6	31.6	75.8

*Value exceeds threshold for application of special lower MBTA standards. (Standards: ≥75% without auto; ≥15% elderly; or ≥60% transfer to another service.)

Latent Demand

Two service goals of the MBTA are to "develop and maintain an effective and efficient network of public transportation services for the benefit of all area residents and visitors" and to "offer the best possible level and quality of service:

- for those now using public transportation
- and to reduce auto usage and attract new customers for transit."[3]

To achieve these goals, the MBTA must provide a basic level of mobility for transit dependent residents, as well as provide service that is an attractive alternative to the automobile.

With only a few exceptions, either bus or rail transit service is provided within a quarter of a mile of all Central North area residents (the exceptions are small pockets only slightly beyond a quarter of a mile from bus or rail routes (see Figure 3)), and major trip generators within and outside of the corridor are also served. In addition, the level of service provided on most CN bus routes is fairly high. Of the fourteen routes, during rush hours, seven have headways of 15 minutes or less, six are on 20 to 25 minute headways, and one is on 30 to 35 minute headways. During mid-day, all routes except one operate on 30 minute headways or less. This combination of service coverage and frequencies should assure that a basic level of service is being provided. Further, relatively high ridership figures (71,200 per weekday for CN routes) and a 27 percent share of all work trips in the corridor for transit indicate that a basic level of service is, in fact, being provided, and also that, on an overall basis, it is well used.

Most CN bus riders are transit dependent in terms of not having a car available for their trip. Riders who own a car but choose instead to ride the bus make up 22 percent of CN bus ridership which, although significant, also indicates that much of this market is not being attracted to the CN bus service as it now operates. A major deterrent to increasing ridership from this market is that waiting times combined with slow running speeds and, in many cases, the necessity to transfer, result in trip times that are much longer than are possible by automobile. In the Central North area, the slow bus running times are a function of street layout, traffic and passenger loads. In some cases, express or "limited" service can increase running speeds,

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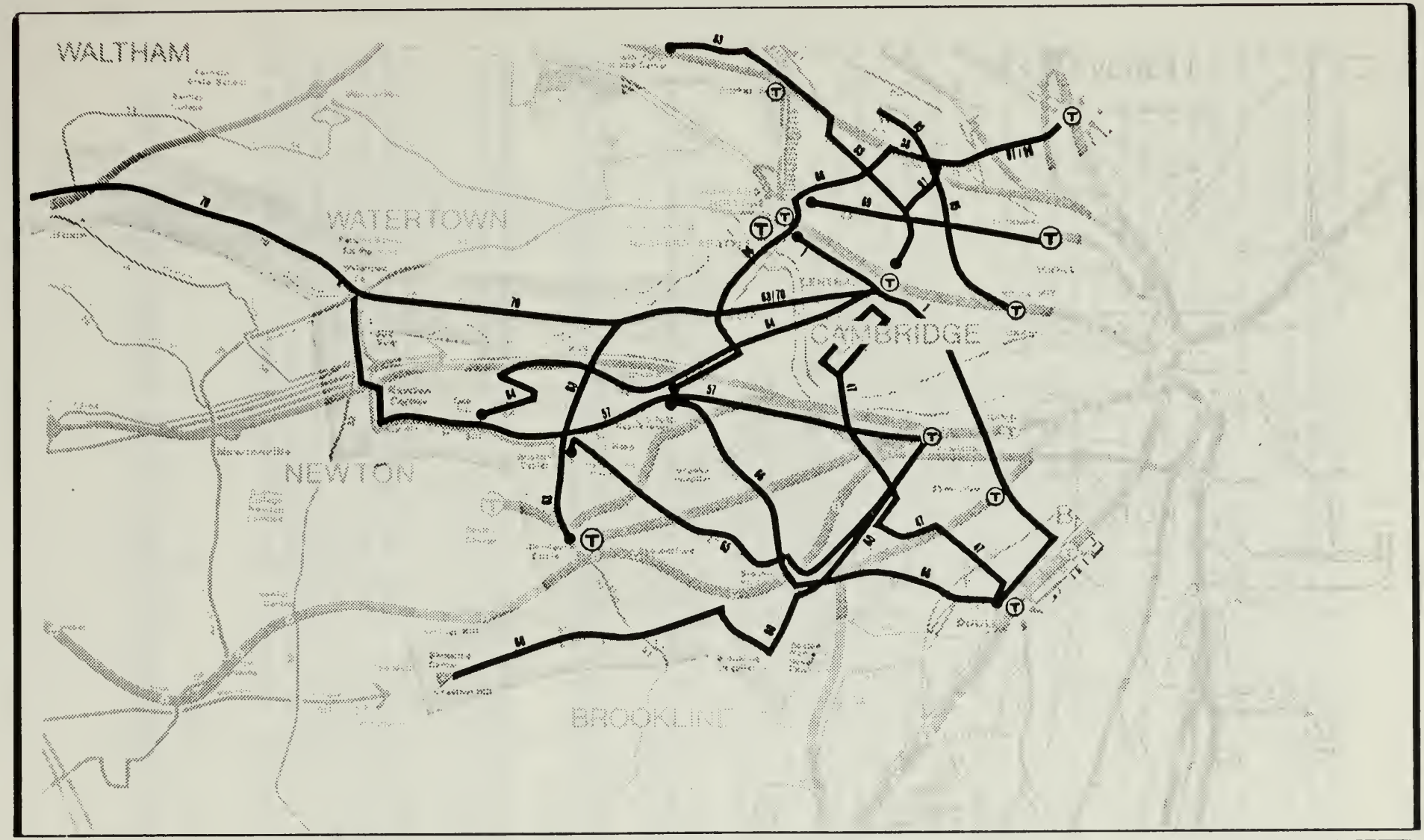
[3]MBTA "Service Policy for Surface Public Transportation," August 5, 1977.



Central North Bus Study	Area Within One-Quarter Mile of Transit Service	CTPS
Market Analysis		FIGURE 3

but considering available street alignments and CN bus boarding and alighting patterns, the opportunity for this type of improvement appears extremely limited in the Central North area.

Although it may not be possible to significantly reduce bus running times on existing routes, other measures can be taken to reduce overall travel times for passengers. These include shorter headways on buses; route variations; or the combination or through-routing of routes to reduce the number of transfers, and timed transfer points to reduce wait time in cases where transfers will occur. In addition, the alignment of a specific route could be changed to make it more direct and thus reduce bus travel time between two points, and/or new routes could be instituted to provide one seat service between interchanges that now require a transfer. Changes of these types could both encourage new ridership and benefit existing riders.

For the purposes of the latent demand analysis, transfer improvements and direct travel along highly traveled "desire" lines were examined in a general sense. (More route specific improvements are examined as part of the route-by-route analysis: CTPS Memorandum "Bus Route Productivity, Efficiency and Reliability," K. H. Quackenbush, January 28, 1987.)

In terms of transfers between routes, the following MBTA service standards and guidelines apply:[4]

- No more than 25 percent of customers using only surface vehicles should require more than one vehicle to complete their trips.
- Two routes with a common terminus and a transfer rate of 20 percent or more should be considered candidates for through-routing.
- Route extensions of one mile or less should be implemented if the extension would eliminate a transfer for 20 percent or more of the route's riders.

At present, 29 percent of CN bus passengers transfer to or from other bus routes, with two percent of these trips involving two or more transfers. (If Green Line surface vehicles were to be counted as "surface vehicles," the transfer percentage would be higher.) Although this percentage is above the MBTA's guideline, the transfers occur among 56 different bus routes (14 of which are the CN routes). The highest number of transfers to and

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[4]MBTA Service Policy for Surface Public Transportation, August 5, 1977.

from any of the CN routes is between Route 1 (Harvard-Dudley) and Routes 42 (Dudley-Arborway) and 77 (Harvard-Arlington Heights), at 1,580 and 1,430, respectively. In terms of transfer rates, however, these transfers amount to only ten percent and nine percent of Route 1's riders, well below the MBTA guidelines for through-routing. Transfer rates for all other CN routes are also well below 20 percent between any two routes. Since the transfers are spread among so many different routes, no route combinations appear warranted solely for the purpose of reducing transfers.

While it may not be possible to significantly reduce the total number of transfers, it may be possible to reduce the amount of time involved in transfering by coordinating bus schedules and creating timed transfer points. Possible locations to convert to timed transfer points would be terminal locations such as Harvard Square, Central Square, Dudley Square, and to a lesser extent, Brighton Center and Union Square in Allston. Schedule coordination is less critical when frequent headways are involved, but can result in significant time savings when long headways are involved. In the Central North area, five of 14 routes operate at 20 minute or longer headways during peak periods, and eight of 14 operate at 30 to 60 minute headways during mid-day and evening periods. Following is a list of route pairs with existing transfers and where both routes have these longer headways:

TABLE 5
Service to Consider for Coordinated Scheduling

Routes	Peak Periods	Mid-day	Evening
60-65	X	X	X
63-83		X	X
63-86		X	X
63-91		X	X
66-86			X
66-65			X
66-47			X
69-83			X
69-91			X
70-91		X	X
70-83		X	X
70-86		X	X
70-64	X	X	
70-47			X
83-47			X
83-91		X	X
83-64		X	
85-91		X	X
91-47			X
91-64		X	X

A third but more expensive method to reduce bus transfers and to generate new ridership would be to institute new routes or to extend existing routes. Although none of the routes appear to meet MBTA guidelines for extension (that transfers for 20 percent or more of a route's riders be eliminated), extensions may be justifiable for other reasons such as to reduce bus presence in Central Square, or to respond to changed travel patterns. In order to examine how well existing transit service matches existing travel patterns (and presumably demand), areas between which 1,000 or more work trips were made in either direction were reviewed with respect to the level of transit service provided.

As can be seen in the summary shown in Table 6, most interchanges are served by direct transit service, and unless noted otherwise, transit usage for that interchange is also consistent with transit usage to and from other nearby and similar areas. Exceptions in the areas covered by this study are

- from the northern section of "South" Allston/Brighton to Downtown Boston, Parker Hill and "North" Allston/Brighton.
- from Central Somerville to East Cambridge and Harvard Square.

South Allston/Brighton is currently served by six bus routes and the Green Line, and as a result, most of the area is served by one or more transit lines. However, in the northern section (north and west of Brighton Center and west of Union Square) most of the routes are oriented toward Cambridge while most of the travel is oriented toward Downtown Boston, the Back Bay, the Fenway and Parker Hill. Two routes, Routes 65 and 66, do serve the Fenway and Parker Hill areas; it may be possible to extend these routes slightly to provide more service coverage to this area.

Service between North and South Allston/Brighton is now served by three routes (Routes 63, 64, and to a lesser extent, Route 86), but transit usage is much lower than to other nearby areas, while the drive-alone percentage is higher. Re-routings of Routes 63, 64 and 86 in Allston/Brighton could possibly increase utilization of these routes, and overall transit usage in Allston/Brighton.

Transit service between Somerville and Cambridge (or lack thereof) was brought up as an issue by public officials in these cities. Census journey-to-work data from 1980 confirms that there are a large number of trips made between the two cities, and recent developments in the Kendall Square area have added approximately 2,000 jobs in that area since 1980, thus further increasing the demand for service. In 1980, the greatest number of work trips between Somerville and Cambridge were made from Central Somerville to East Cambridge (1,777) and to Harvard

TABLE 6

Summary of Transit Service Between Interchanges
with 1,000 or More One-Way Work Trips

	Interchange	# One-Way Work Trips (all modes)	Transit Connections	Comments
1.	S. Allston/Brighton to Boston CBD	5,409	Green Line and Route 301 direct	High transit mode split (69%), but no direct service from north of Brighton Center
2.	Back Bay to Boston CBD	3,324	Green Line direct	
3.	Fenway to Boston CBD	2,756	Green Line direct	
4.	Central Brookline to Boston CBD	2,597	Green Line direct	
5.	Central Somerville to Boston CBD	2,126	Rt. 89 to Orange Line; Rts. 80, 87, 88 to Green Line; Rt. 85 to Red Line	Rts. 80, 87, 88, 89 examined in Northwest Corridor Service Study[1]
6.	S. Allston/Brighton to Back Bay	1,920	Green Line	High transit mode split (60%), but no direct service from north of Brighton Center
7.	Central Somerville to E. Cambridge	1,777	Rt. 85 direct; Rts. 83, 91 to Red Line or walk	Rt. 85 serves only small part of Central Somerville; relatively low transit mode split (28%), high percentage of drive-alone (47%) workers
8.	Central Square to Boston CBD	1,735	Red Line direct	
9.	S. Allston/Brighton to Fenway	1,659	Green Line and Rt. 57 direct	
10.	Central Square to E. Cambridge	1,642	Red Line direct	

[1]Cambridge Systematics, Inc., January 1985.

	Interchange	# One-Way Work Trips (all modes)	Transit Connections	Comments
11.	Central Brookline to Parker Hill	1,528	Green Line and Rts. 60, 65 direct	
12.	W. Somerville to Boston CBD	1,515	Rt. 89 to Orange Line; Rts. 80, 87, 88 to Green Line; Red Line direct	Rts. 80, 87, 88, 89 examined in Northwest Corridor Service Study
13.	Central Square to Harvard Square	1,508	Red Line direct Route 1 direct	
14.	Fenway to Back Bay	1,469	Green Line direct	
15.	N. Brookline to Boston CBD	1,289	Green Line direct	
16.	S. Allston/Brighton to Parker Hill	1,274	Rts. 65, 66 direct; Rts. 63, 57, to Rt. 65; Rt. 64 to Rt. 66	No direct service north or west of Brighton Center except in Union Square area
17.	S. Allston/Brighton to N. Allston/Brighton	1,228	Rts. 63, 64 direct; Rts. 64, 57, 66 to Rt. 86	Relatively low transit mode split (28%), and relatively high drive-alone share (49%)
18.	N. Cambridge to Harvard Square	1,207	Red Line direct; Rt. 74, 78 direct	
19.	Harvard Square to Downtown	1,198	Red Line direct	
20.	Central Brookline to Fenway	1,153	Green Line direct	
21.	N. Cambridge to E. Cambridge	1,140	Red Line direct; Rts. 83, 78, 74 to Red Line	Rts. 74, 78 examined as part of Northwest Corridor Service Study

	Interchange	# One-Way Work Trips (all modes)	Transit Connections	Comments
22.	Central Somerville to Harvard Square	1,139	Rt. 86 direct	Rt. 86 only serves southeast corner of Central Somerville. Most of area has no direct or good connecting service. Transit mode share is 28%; auto 18%; walk 39%
23.	E. Cambridge to Central Square	1,128	Red Line direct	
24.	E. Somerville to Downtown	1,084	Rts. 89, 101 to Orange Line; Rts. 80, 88 to Green Line; Rt. 85 to Red Line	Rts. 80, 88, 89, 101 examined as part of Northwest Corridor Service Study
25.	N. Cambridge to Downtown	1,065	Red Line direct; Rts. 83, 74, 78 to Red Line	Rts. 74, 78 examined as part of Northwest Corridor Study
26.	E. Cambridge to Downtown	1,019	Red Line direct; Green Line direct	

Square (1,128),[5] while the two cross-town routes between the two cities operate essentially from East Somerville (Sullivan Square) to Central Square and Harvard Square. At present, 47 percent of those traveling between Central Somerville and East Cambridge drive alone, and 57 percent of those traveling to Harvard Square drive alone. By contrast, only 32 percent of all workers from other Central North areas drive alone to East Cambridge, and only 26 percent drive alone to Harvard Square.

Lastly, East Cambridge, in addition to attracting a large number of trips from Somerville, also attracts a significant number of trips from other Central North areas. In most cases, more trips are made to East Cambridge than to the neighboring Central Square area; however, the greater bus presence is in Central Square. The City of Cambridge has expressed the desire to reduce the number of buses laying-over in Central Square as well as to increase service to Kendall Square. One solution to this problem may be in extending or re-routing Central Square routes to Kendall Square. Extension of routes from Central Square to Kendall Square would increase service coverage without reducing service to Central Square, while re-routing would reduce service to Central Square but provide more direct service to the Kendall Square/MIT areas.

Summary

The Central North corridor is an area with well established travel patterns, and a well established transit network. With the exception of a few small areas, all of the corridor's residents are within a quarter of a mile of either MBTA bus or rail service. There is a high degree of transit dependency in the corridor, and a high level of transit ridership. To a significant extent, it can probably be assumed that many of the area's residents have choosen their place of residence based on the availability of transit. However, while the system is well established and many riders depend on it for daily transportation, changes may still be possible that improve the system for these existing riders, as well as bring new riders to the system. These types of changes are as listed below:

- reduction in the number of transfers necessary, through route variations, re-routing or route extensions, particularly in the Central Square and Kendall Square areas of Cambridge, and in Allston/Brighton. (These areas are addressed as part of the Cambridge-Somerville analyses and the productivity analysis.)

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[5]Excluding internal trips within the Central Square and Harvard Square areas.

- schedule coordination between routes with long headways, such as Routes 60, 63, 64, 65 and 85. (This area is addressed in the memorandum on coordination possibilities.)

- implementation of timed transfer points at major transfer locations such as Central Square, Harvard Square, and Dudley Square, and also possibly Brighton Center and Union Square in Allston.

- improved service between Allston/Brighton and the Parker Hill area of Boston.

- additional cross-town service between Somerville and Cambridge. (This area is addressed in the Somerville/ Cambridge cross-town analysis.)

- improved service for trips made within Allston/Brighton, particularly in the north-south direction.

- additional service to Kendall Square in Cambridge. (This area is addressed in the Central Square/Kendall Square bus analysis.)

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APPENDIX I
KENDALL SQUARE/CENTRAL SQUARE BUS SERVICE

CTPS

State Transportation Building
10 Park Plaza, Suite 2150
Boston, MA 02116-3968
(617) 973-7100

CENTRAL
TRANSPORTATION
PLANNING
STAFF

MEMORANDUM

TO: Central North Bus Study Files June 22, 1987

FROM: Geoff Slater

RE: Kendall Square/Central Square Bus Service

Since the early 1980's, a large amount of commercial development has occured in the Kendall Square area. To serve the area's increasing employement, Cambridge officals have requested that additional transit service be provided to Kendall Square. In addition, the City has also expressed an interest in reducing bus presence in Central Square.[1] Due to the proximity of the two areas, and the obvious possibility of re-routing or extending some Central Square service to Kendall Square to serve both purposes, these two issues have been addressed jointly.

To provide additional service to Kendall Square, two major options were examined: (1) the extension of Central Square routes to Kendall Square via MIT, and (2) new service along four different alignments through Somerville from Sullivan Station, Wellington Station and Medford Square. To reduce bus presence in Central Square, in addition to extending Central Square routes to Kendall Square, a reduction in layover time spent in Central Square through schedule adjustments, and the combination of routes now terminating in Central Square were also examined.

A summary of the findings of this analysis is presented below. More detailed information is in Attachment A.

Summary of Findings

In addition to providing new service to Kendall Square, the extension of Central Square routes to Kendall Square would also reduce bus presence in Central Square, as desired by Cambridge officials. Further, the extension of Central Square routes would provide new service to Kendall Square at a lower cost than would the implementation of entirely new routes. However, the extension of any of the routes would

[1] In addition to reductions implemented since 1984. See CTPS Technical Memorandum "Central Square Bus Service Improvements: Existing Conditions, Alternatives and Recommendations," Sonia Weinstock, July 17, 1984.

increase the MBTA's operating costs and deficit. Therefore the degree to which service increases to Kendall Square and reductions in bus presence in Central Square are desired must be weighed against the willingness of the MBTA and the City of Cambridge to pay the increased costs. On this basis, and as summarized below, the extension of Routes 91, 70 (peak period service only), and 64 could best meet the dual objectives of providing additional service to Kendall Square and reducing bus presence in Central Square, at the most reasonable cost. Comparison data for these and all other alternatives examined are also presented in Table 1.

Route 91: An extension of Route 91 could generate from 500 to up to 1120 new transit trips to the Kendall Square/MIT area (which would be the largest increase possible under any of the alternatives examined), and result in a 15 percent reduction in bus presence in Central Square. Due to the relatively large increase in ridership, the resulting increase in MBTA operating costs could be as low as $180 per day. One disadvantage of this extension is that the the routing to Kendall Square would be fairly indirect. However, it would still be more direct than any existing services, and would also allow service to most of the MIT campus, which would result in much of the ridership increase.

Route 70: An extension of Route 70 would not generate a significant number of new transit trips (approximately 210 per day), but would result in a large reduction in bus presence in Central Square. If schedules were adjusted to insure 90 percent on-time departure performance (see Attachment A, Section 3.1), an average of one Route 70 bus would be laying over in Central Square at any given time during the PM peak. Although it would be difficult to justify the extension of all Route 70 buses to Kendall Square on the basis of ridership, the extension of peak-period buses only may be justifiable on the basis of the reduction in bus presence that would result. The extension of peak-period buses only would result in a reduction in bus presence of 23 percent for both peak periods combined, and a 33 percent reduction in the PM peak. The cost of extending peak-period service to Kendall Square would be $190 per day.

Route 64: Route 64 is currently the second lowest performing route in the Central North (CN) area (in terms of Passengers per Vehicle Service Hours and per Vehicle Service Mile). The extension of this route should result in a large improvement in the productivity of Route 64, and would also provide for a modest reduction in bus presence in Central Square (11 percent per day). With an extension to Kendall Square,

	Extensions from Central Square to Kendall Square on:						New Service to Kendall Square*				
	Route 47	Route 63	Route 64	Route 70	Route 83	Route 91	Route A	Route B	Route C	Route D	Rt 69 Ext
1. % Reduction in Layover Time in Central Square**											
a. All Day	19%	10%	11%	21%	24%	15%	NA	NA	NA	NA	NA
b. Peak Periods	19%	11%	10%	23%	25%	13%	NA	NA	NA	NA	NA
2. Operating Cost	$509	$395	$333	$533	$586	$585	$1,411	$1,599	$1,849	$2,006	$458
3. Ridership											
a. New Transit Riders	466	153	99	210	168	1121	526	678	673	1010	46
b. Shift from Other Transit	231	104	568	154	612	279	1068	1038	1307	2197	162
c. Pass. Remaining Onboard	0	132	90	50	208	47					
d. Total	697	389	757	414	988	1447	1594	1716	1980	3207	208
4. Farebox Revenue											
a. Gain from New Transit Riders	$176	$61	$38	$75	$60	$424	$200	$258	$256	$384	$17
b. From Existing Transit Riders	$88	$40	$216	$59	$233	$106	$406	$394	$497	$835	$62
c. Loss due to Shift fr Rail to Bus	($16)	($7)	($40)	($11)	($43)	($20)					
d. Total	$248	$94	$214	$123	$250	$510	$606	$652	$753	$1,219	$79
5. Productivity of Extensions											
a. Passengers/VSH	60.1	48.8	102.6	24.1	84.4	117.2	48.3	45.9	45.8	68.4	19.4
b. Passengers/VSM	5.4	4.4	9.3	3.1	7.6	10.6	4.8	4.6	4.6	6.8	1.9
6. Financial Performance											
a. Farebox Return***	51.8%	25.4%	76.2%	25.1%	49.9%	90.6%	42.9%	40.8%	40.7%	60.8%	17.2%
b. Operating Cost/Passenger	$0.73	$1.02	$0.44	$1.29	$0.59	$0.40	$0.89	$0.93	$0.93	$0.63	$2.20
c. Operating Cost/New Rider	$1.09	$2.58	$3.36	$2.54	$3.49	$0.52	$2.68	$2.36	$2.75	$1.99	$9.96
d. Net Impact on T Operating Costs****	$349	$341	$335	$469	$569	$181	$1,211	$1,341	$1,189	$1,218	$441

* Figures based upon mid-range estimates
** Based upon adjustments to minimize layover time while insuring 90% on-time departures.
*** Does not include impact of revenue loss on other MBTA services.
**** Figures for Routes C and D assume replacement of Route 85 with new route. The elimination of Route 85 would save $404 per day.

Central North Bus Study Central Sq/Kendall Sq Analysis	SUMMARY OF WEEKDAY OPERATING STATISTICS FOR CENTRAL SQUARE AND KENDALL/MIT ALATERNATIVES	TABLE 1

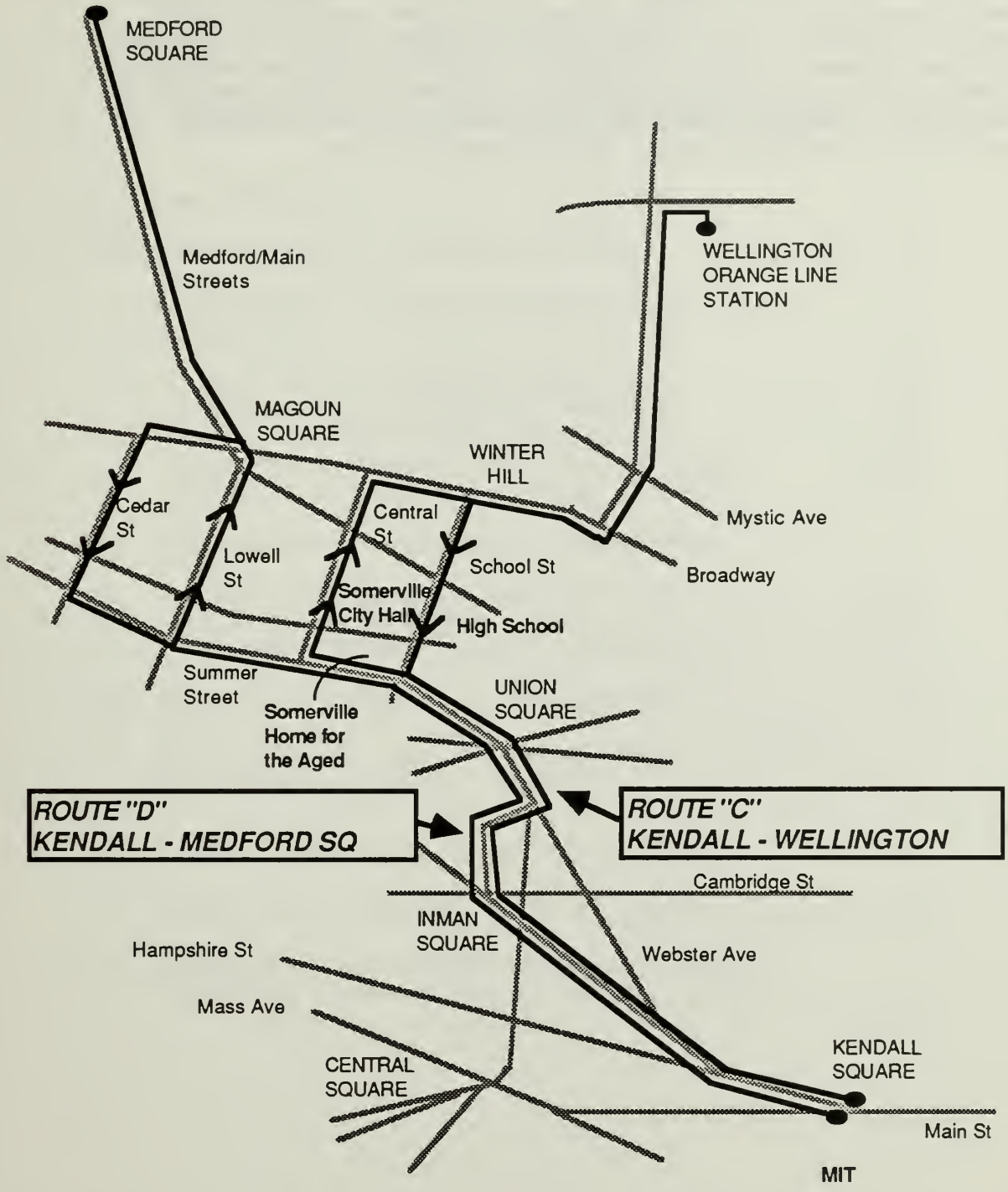
ridership on Route 64 could increase by 924 trips per day (a 60 percent increase), with 250 of these trips being new transit trips. The net operating cost of this extension would be $330 per weekday.

In addition to providing additional service to the Kendall/MIT area through these extensions of existing routes, a demand for service from Somerville and Medford also exists. New service between Wellington Station and Kendall Square, or between Medford Square and Kendall Square, could perform well within the range of other CN bus service. Of the four routes examined between these areas, two could serve unique markets containing interchanges that are currently not well connected by transit. A summary of these two routes (as shown in Figure 1) is as follows:

Wellington - Kendall Square: This route would provide service between Kendall Square and Wellington Station via Inman Square, Union Square, City Hall and Ten Hills. It would serve essentially all of the market currently served by Route 85 with a higher level of service, plus provide extended service to Wellington which would serve much of Central Somerville. At a level of service of 92 trips per day, this route would attract 2,000 passenger trips per day. Assuming Route 85 would be replaced by this route, the net cost of operating this route would be $1,189 per weekday.

Medford Square - Kendall: This route would operate between Kendall Square and Medford Square via Inman Square, Union Square, Summer Street, Lowell Street, and Main Street. As with the Wellington to Kendall route, this route would also serve essentially all of the market now served by Route 85 but at a higher level of service (92 trips per day assumed). This route would have the highest ridership of the routes examined, at 3,200 per day (based upon the mid-range estimate), with 1,000 of the trips made by new transit riders. Assuming that this route would replace Route 85, the net increase in operating costs would be $1,218 per day.

To reduce bus presence in Central Square, other than extending some routes to Kendall Square, very little can be done. On an overall basis, bus service in Central Square is already scheduled so as to minimize bus layovers there. Further reductions would require a relocation of some layovers away from Central Square. Considering ridership on the six Central Square routes (Routes 47, 63, 64, 70, 83 and 91), and current service levels, removal of layovers through significant reductions in service or re-routings away from Central Square would not be appropriate. Further, due to the



Central North Bus Study Central Sq/Kendall Sq Analysis	ADDITIONAL SERVICE TO KENDALL SQ. Kendall Square - Wellington & Kendall Square - Medford Square	CTPS FIGURE 1

operating environments of the six routes, all routes experience a high degree of running time variability that would preclude the combination of routes terminating in Central Square into single longer routes operating through Central Square. As a result, the most effective method of reducing bus presence in Central Square without adversely impacting service would be to extend service on Routes 63, 70 and 91 to Kendall Square, as discussed above.

Attachment A

Central Square/Kendall Square Bus Service - Supplemental Data and Analysis Methodology

1 EXISTING SERVICES A1

2 ADDITIONAL SERVICE TO KENDALL SQUARE A2

2.1 Extensions of Central Square Routes to Kendall/MIT A3

Ridership on Extended Routes..... A4
Productivity of Extended Routes..... A6
Impact on MBTA Operating Costs..... A7
Impact on Layovers in Central Square..... A9
Summary of Findings, Overall Impacts..... A10

2.2 New Service from Somerville/Medford A12

Potential Ridership on New Routes..... A13
Productivity of New Routes..... A16
Financial Performance of New Routes..... A17

2.3 Extension of Route 69 from Lechmere A19

2.4 Additional Service to Kendall/MIT - Summary of Findings, Overall Impacts A20

3 REDUCTION OF BUS PRESENCE IN CENTRAL SQUARE A22

3.1 Reduction of Layover Time at Central Square.. A23

3.2 Combination or Through-Routing of Routes Currently Terminating in Central Square A28

1 EXISTING SERVICES

The Central and Kendall Square areas are currently served by nine MBTA bus routes and the Red Line. The bus routes are as follows:

TABLE A-1
Central and Kendall Square Bus Routes

Route	Description
1.0	Harvard Sq - Dudley Sq
1.1	Harvard Sq - Boston City Hospital
47.0	Central Sq - Boston City Hospital
63.0	Central Sq - Cleveland Circle
63.1	Central Sq - Cleveland Circle via Oak Sq
64.5	Central Sq - Oak Sq
69.0	Harvard Sq - Lechmere
70.0	Central Sq - Cedarwood, Waltham
70.2	Central Sq - Watertown Sq
83.1	Central Sq - Spring Hill, Somerville
91.0	Central Sq - Sullivan Station

Six of these routes (Routes 47, 63, 64, 70, 83, and 91) terminate and lay over in Central Square. Route 1 operates through Central Square and by MIT along Massachusetts Avenue. Kendall Square is directly served only by Route 85, and Route 69 operates along the outskirts of both areas (Central Square and Kendall Square). As of the Fall of 1984, 859 bus trips on Routes 1, 47, 63, 64, 70, 83, and 91 carried 14,580 unlinked passenger trips in and out of Central Square daily, while 311 daily trips on Routes 1 and 85 carried 1,770 passenger trips in and out of the Kendall/MIT area.

The higher level of bus service and bus usage in Central Square has a historical basis. Central Square was established earlier than Kendall Square and has long attracted a large number of trips from throughout the Central North area. Beginning in the 1800's, horse-drawn trolley lines were implemented to serve that demand, and the combination of these routes created a network that made other areas accessible and attracted more trips through Central Square. Although modes have changed and routes have been modified, most of the existing MBTA routes in Central Square have their origins in those original routes.

To date, Central Square bus routes continue to serve a large number of trips to and from Central Square, and through Central Square as a transfer point to other destinations. Based on passenger counts and surveys conducted in the Fall of 1984, 6,810 trips are made daily to and from Central

Square proper on CN bus routes, and another 7,700 passenger trips involved a transfer through Central Square, most of which were either to the Red Line (51.7 percent) or other MBTA buses (45.8 percent).

2 ADDITIONAL SERVICE TO KENDALL SQUARE

Additional service to Kendall Square would require either new routes, or the extension of existing routes.[1]

New routes from areas south and southwest of Kendall Square (Back Bay, Fenway, Parker Hill, Roxbury, Allston/Brighton and Brookline) would provide service from essentially the same areas as the Central Square routes operate in, and due to the limited number of streets suitable for bus service in these areas, they would have to be similar in alignment to the existing Central Square routes. As a result, from those areas, the extension of Central Square routes was considered rather than the implementation of new routes.

From west and northwest of Kendall Square (Central Square, Harvard Square, North Cambridge and West Somerville), most areas are already linked to the Kendall/MIT area by the Red Line or bus connections to the Red Line. In these areas, transit ridership to Kendall/MIT is already fairly high, and additional bus service from these areas would likely draw much of its ridership from the Red Line rather than generating a significant number of new transit trips.

Areas to the north of Kendall Square (Central Somerville and East Somerville), however, for the most part currently have only indirect service, and with the exception of Route 85 users, transit riders must take a bus to the rail transit system to travel to Kendall Square. Presumably as a result of this indirect service, transit usage from these areas is significantly lower than from other surrounding areas. Therefore, additional service from Central and/or East Somerville (including possible changes to Route 85) would have the potential to attract riders from areas not well served. In addition, an extension of Route 69 from Lechmere could also provide additional service from areas of Cambridge that are not well linked with Kendall Square (except at the Harvard Square end) at a relatively low cost.

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[1] In this analysis, all route extensions from Central Square are assumed to be routed along Massachusetts Avenue to Vassar Street to Main Street, in order to serve MIT.

2.1 Extension of Central Square Routes

The extension of Central Square routes to Kendall Square would have a number of impacts. First, it would remove all layovers on that route from Central Square and move them to Kendall Square. Second, increased bus service to Kendall Square would also increase bus ridership to the Kendall Square/MIT area. Some of the new ridership would be new transit ridership, but much of it would simply shift from the rail transit system to the new bus service. For these latter riders, the extension of service could also eliminate a transfer from bus to rail, which would effectively reduce the fare for those patrons, and also revenues collected by the MBTA. Third, the extension of routes would increase MBTA operating costs slightly, only part of which would be offset by increased revenues.

For both Central Square and Kendall/MIT, the number of work trips made between each area and locations directly served[2] by Central Square routes is fairly high (see Table A-2). Total transit usage to the two areas was also fairly high even though the level of transit service to Kendall/MIT is much lower than to Central Square. However, other than these similarities, travel patterns to and from the two areas differ significantly. For Central Square, work trips are split fairly evenly between directions. Almost as many work trips are made by Central Square area residents to work locations outside of the Central Square area (49 percent) as are made by persons living elsewhere to work locations in Central Square (51 percent). For the Kendall/MIT areas, the large majority of all work trips (89 percent) are made from home locations outside of the Kendall/MIT area to work locations in Kendall Square or at MIT. Very few of the area's residents make work trips to other areas served by Central Square routes (only 11 percent).

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[2] A census tract was considered to be directly served if a route travelled through the tract, or if a majority of the census tract's area was within one-quarter of a mile of the route.

TABLE A-2
1980 Works Trips To/From Central Square and Kendall/MIT

To/From Areas Directly Served by Route	To/From Central Sq		To/From Kendall/MIT	
	Total Trips	% by Transit	Total Trips	% by Transit
47	2,120	56.2%	1,020	49.1%
63	1,100	37.3%	800	41.4%
64	1,280	33.6%	1,290	33.6%
70	2,100	41.1%	1,230	26.5%
83	4,780	21.6%	3,760	29.4%
91	1,980	36.2%	2,900	18.4%
Total	13,360	34.8%	11,000	29.4%

In addition, the transit mode used differs significantly. Between Central Square and areas served by Central Square routes, approximately 75 percent of all transit trips are made by bus, while only 27 percent of all transit trips are made by bus between those same areas and Kendall/MIT. As would be expected, since most of the Central North area is connected to Kendall/MIT by the rail transit system, but not by bus, most transit trips to and from Kendall/MIT are made by rail transit (73 percent). Similarly, the areas with the lowest degree of direct access to the rail system (along Routes 70 and 91 (except at Sullivan Square)) have the lowest degree of transit use to Kendall/MIT.

Ridership on Extended Routes Because the transit mode split to Kendall/MIT is already fairly high, the extension of Central Square routes to Kendall/MIT would, to a certain extent, result in a shift of riders from rail transit to bus transit, as well as generating new ridership. At present, both bus and rail transit compete with automobiles and other modes for trips to and from Central Square, while for the most part, only rail transit competes with automobiles and other modes for trips to Kendall/MIT. If all six Central Square routes were extended to Kendall/MIT, that area's workers and residents would be presented with the same choices as are Central Square travelers. Since relative costs and travel times would be essentially the same to Kendall/MIT as to Central Square, it would be expected that the overall transit mode split to and from Kendall/MIT would be similar to the mode split to and from Central Square. In terms of individual routes, the same should also be true - if Central Square routes were extended, a similar bus mode split would be expected to Kendall/MIT as is presently carried to Central

Square.[3] On this basis, projected ridership increases (including both new riders and those who shifted from rail) on each of the extended Central Square routes, would be as follows:

TABLE A-3
Estimates of Total Ridership on Extensions

	New Transit Riders	Shift from Rail Transit	Current Riders Remaining On Board	Total
Route 47	470	230	0	700
Route 63	150	100	130	380
Route 64	100	570	90	760
Route 70	210	150	50	410
Route 83	170	610	210	990
Route 91	1120	280	50	1450
	2220	1940	530	4690

As summarized in this table, the total increase in CN bus ridership, if all routes were extended, is estimated at up to 4160 additional unlinked passenger trips per day. Slightly over half of these trips (2220) would be made by new transit riders, while the others (1940) would be made by current transit users that would shift from rail transit. In addition to these new riders, approximately 530 existing CN bus riders would stay on board past Central Square to utilize extended service.

Of the six routes, ridership increases could be significantly higher on Route 91 than on any other route. Large projected increases on this route would result from the direct connection of two areas, between which a large number of trips are made, that are now only indirectly connected by transit. Although the routing of the extension from Central Square to Kendall Square via MIT would be still somewhat indirect, a one-seat ride could be provided, and most travel times would be lower than on other existing services. Even if an extended Route 91 performed at a much lower level, ridership would still be significant. Assuming the extension of Route 91 performed at a level

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[3] In summary, to do this, CN survey data were used with 1980 Census data projected to 1984 to determine the bus mode split of the total work trip market in 1984, and then bus mode split figures for Central Square were applied to the total number of work trips to and from Kendall/MIT. Finally, a factor for non-work trips was applied to estimate the total number of work and non-work trips.

similar to Route 63 (the lowest performing of the Central Square routes), the ridership increase would be 720 trips per day (495 new trips, 225 shift from rail).

Productivity of Extended Routes. Based upon Fall 1986 schedules, Routes 47, 63, 64, and 70 have excess capacity that could accommodate the additional ridership that would result from the extensions. On Routes 83 and 91, additional service would have to be provided during peak periods. In order to limit maximum loads to an average (per time period) of no more than 60 persons, one additional round trip would have to be provided on both Route 83 and 91 during the AM and PM peak periods. Including these additional trips, the productivity of each of the extensions in terms of passengers per vehicle service hour (Pass/VSH) and per vehicle service mile (Pass/VSM) would be as follows:

TABLE A-4
Performance of Extended Routes (All Day)[4]

	Pass/VSH		Pass/VSM	
	Fall 1984 (Actual)	Extended (Estimated)	Fall 1984 (Actual)	Extended (Estimated)
Route 47	84.3	81.6	10.6	9.9
Route 63	57.8	52.5	6.2	5.4
Route 64	45.2	53.0	5.1	5.7
Route 70	63.0	59.1	6.2	5.8
Route 83	91.7	84.6	12.3	10.6
Route 91	62.0	72.3	8.3	8.7

As can be seen from Tables A-3 and A-4, increases in bus ridership would be greatest on Routes 91 and 83 (1450 and 990, respectively), but relative to the amount of service provided, increases in bus productivity would be highest on Routes 91 and 64. In all cases, route productivity would remain above MBTA performance objectives.

A third method used to assess the productivity of route extensions was through use of the Passengers/VSM and Passengers/

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[4]Estimates assume a routing from Central Square to Kendall Square along Massachusetts Avenue to Vassar Street to Main Street to the Kendall/MIT Red Line station, at a distance of approximately 1.2 miles and an average speed between the two areas of 11 miles per hour, (resulting in a travel time to Kendall/MIT of 6.5 minutes each way). This alignment was chosen instead of one directly down Main Street in order to serve MIT.

VSH figures for the segment between Central Square and Kendall/MIT terminal. On this basis, the productivity of the extensions themselves would be as follows:

TABLE A-5
Performance between Central Square and Kendall/MIT (All Day)

	Pass/VSH		Pass/VSM	
	Fall 1984 Total Route (Actual)	C. Sq-K/MIT Segment (Estimated)	Fall 1984 Total Route (Actual)	C. Sq-K/MIT Segment (Estimated)
Route 47	84.3	60.1	10.6	5.4
Route 63	57.8	48.8	6.2	4.4
Route 64	45.2	102.6	5.1	9.3
Route 70	63.0	24.1	6.2	3.1
Route 83	91.7	84.4	12.3	7.6
Route 91	62.0	117.2	8.3	10.6

As for the routes as a whole, performance for the Central Square to Kendall/MIT segment would be higher than Fall 1984 performance only on routes 64 and 91. However, on Routes 47 and 83, even though performance would be lower than on the rest of the route, performance would still be relatively high by most standards. On Routes 63 and 70, ridership would be lower to the extent that extension of either route would not be warranted on the basis of ridership alone.

Impact on MBTA Operating Costs. Based on the MBTA's estimated costs for 1986,[5] an extension from Central Square to Kendall/MIT would cost $4.77 per one-way bus trip. Revenue would be affected in two ways: for new riders attracted to the system, new revenue would be generated; for riders who shifted from the rail system, a lower fare would be collected. Based upon CN survey data and the fare differential between bus and rail transit, each new rider would result in approximately 38¢ of new revenue per trip, but each rider who shifted from rail to bus would result in a revenue loss of about 7¢. On this basis, the daily costs and net revenues generated by extending each route would be as detailed in Table A-6 and summarized in Table A-7.

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[5]Based on 1986 MBTA operating costs at: (1.32 recovery/layover/pull in-out factor * 24.20 per VSH * VSH's) + (1.06 recovery/layover/pull in-out factor * $1.02 per VSM * VSM's).

TABLE A-6

NET FINANCIAL IMPACT OF CENTRAL SQUARE TO KENDALL/MIT EXTENSIONS
(DAILY COST/NET REVENUES OF EXTENSIONS)

	*COST OF ADDITIONAL SERVICE**					*REVENUE*					
	One-Way Trips	One-Way Length	Veh Ser Miles	Veh Ser Hours**	Additional Cost***	Gain from New Transit Ridership	Loss due to Shift from Rail to Bus	Additional Revenue	Net Cost	Farebox Return	Net Cost Per New Transit Rider
Route 47.0											
Peak	26	1.2	31.2	2.8	$124	$51	($5)	$47	$77	37.6%	$0.57
Off-Peak	81	1.2	97.2	8.8	$385	$125	($11)	$113	$272	29.4%	$0.82
All Day	107	1.2	128.4	11.6	$509	$176	($16)	$160	$349	31.4%	$0.75
Route 63/63.1											
Peak	24	1.2	28.8	2.6	$114	$28	($3)	$25	$90	21.6%	$1.28
Off-Peak	59	1.2	70.8	6.4	$281	$33	($4)	$29	$251	10.4%	$3.02
All Day	83	1.2	99.6	9.0	$395	$61	($7)	$54	$341	13.7%	$2.22
Route 64.5											
Peak	24	1.2	28.8	2.6	$114	$18	($19)	($1)	$115	-0.8%	$2.42
Off-Peak	46	1.2	55.2	5.0	$219	$20	($21)	($1)	$220	-0.5%	$4.25
All Day	70	1.2	84.0	7.6	$333	$38	($40)	($2)	$335	-0.6%	$3.37
Route 70.0/70.2											
Peak	40	1.2	48.0	4.3	$190	$30	($4)	$26	$165	13.4%	$1.97
Off-Peak	72	1.2	86.4	7.8	$343	$45	($7)	$39	$304	11.3%	$2.41
All Day	112	1.2	134.4	12.1	$533	$75	($11)	$64	$469	12.0%	$2.23
Route 83.1											
Peak	42	1.2	50.4	4.6	$263	$26	($19)	$7	$255	2.8%	$3.43
Off-Peak	68	1.2	81.6	7.4	$324	$33	($24)	$9	$314	2.9%	$3.37
All Day	110	1.2	132.0	11.9	$586	$60	($43)	$17	$570	2.9%	$3.40
Route 91.0											
Peak*	35	1.2	42.0	3.8	$210	$160	($7)	$152	$57	72.7%	$0.14
Off-Peak	79	1.2	94.8	8.6	$376	$264	($12)	$252	$124	67.0%	$0.18
All Day*	114	1.2	136.8	12.4	$585	$424	($20)	$404	$181	69.0%	$0.16
Total/Average											
Peak	191	1.2	229.2	21	$1,015	$313	($58)	$256	$759	25.2%	$0.91
Off-Peak	405	1.2	486.0	44	$1,927	$520	($79)	$441	$1,486	22.9%	$1.07
All Day	596	1.2	715.2	65	$2,942	$834	($136)	$697	$2,245	23.7%	$1.01

* With the exception of Routes 83 and 91, costs refer to the costs of the extensions only. For Routes 83 and 91, costs also include the cost of two additional round trips that would be necessary to handle the increased passenger loads. The cost of these two additional round trips would be $63 per day on Rt 83 and $43 per day on Rt 91.

** Based on average speed of 11 mph and one-way run time of 6.5 minutes.

*** Based on 1986 MBTA operating costs at: (1.32 recovery/layover/pull in-out factor * $24.20 per VSH * VSH's) + (1.06 recovery/layover/pull in-out factor * $1.02 per VSM * VSM's).

TABLE A-7
Daily Costs and Net Revenues for Route Extensions

Route	Operating Costs	Net New Passenger Revenues	Net Cost	Net Rev /Cost Ratio	Subsidy/ New Transit Rider
47	$509	+$160	$349	34.4%	$0.75
63	395	+ 54	341	13.7%	2.22
64	333	- 2	335	-0.6%	3.37
70	533	+ 64	469	12.0%	2.23
83	586	+ 17	570	2.7%	3.40
91	$585	+$404	$181	69.0%	$0.16

Of the six routes, only one (Route 91) would perform at a level consistent with other Central North bus service in terms of revenue to cost ratio and the cost per rider. The remaining five would perform at a significantly lower level, and on Route 64, due to a large shift from rail to bus, no new revenue would be generated.

Impact on Layovers in Central Square. As further discussed in Section 3.1, MBTA buses currently lay over in Central Square for a total of 1660 minutes per weekday. Some reductions could be made to layover time in some periods, but layover time for some routes also needs to be increased during certain periods, which would increase layover time slightly to 1668 minutes. If all of these adjustments were made, layover time would then be distributed as follows:

TABLE A-8
Layover Time in Central Square as a Percent of Total by Time Period

Route	Early Morn	AM Peak	Mid-day	School Peak	PM Peak	Early Eve.	Night	All Day
47	20%	16%	15%	21%	21%	10%	28%	19%
63	12%	10%	10%	6%	12%	6%	18%	10%
64	17%	14%	17%	8%	7%	18%		11%
70	26%	12%	14%	28%	33%	20%	18%	21%
83	12%	36%	23%	21%	15%	28%	31%	24%
91	13%	13%	22%	15%	12%	18%	5%	15%
Total	100%	100%	100%	100%	100%	100%	100%	100%

If a route were to be extended to Kendall/MIT, the reduction in layover time by time period would be the percentage shown in the table. Therefore, strictly in terms of reducing layover time in Central Square, the extension of Routes 47, 70 and 83 would be most effective on an all day basis. During peak periods, the extension of Route 70 and 83 would be most effective.

Extension of Central Square Routes - Summary of Findings, Overall Impacts

Route 47 An extension of Route 47 would generate up to 470 new transit trips per day, which would be the second highest increase possible by extension of any of the routes (and would also cause a shift of 231 trips per day from rail transit). The extension of Route 47 would also reduce overall bus presence in Central Square by 20 percent. In the AM and PM peaks, the reductions would be 16 and 21 percent, respectively, which would be the second highest reductions possible in either time period. However, the increase in ridership could slightly worsen existing crowding problems. Also, an extension at the Central Square end, coupled with an extension at the City Hospital end, as is now being considered, could worsen existing reliability problems. The financial impact of the extension would be to increase MBTA operating costs by $509 per day, of which $160 would be offset by increase revenues, for a net increase of $349 per day.

Route 63 An extension of Route 63 (both variations) to Kendall Square would have relatively little impact on reducing bus presence in Central Square. If schedules were optimized to reduce recovery time in Central Square, Route 63 would account for less than 11 percent of all layover time on an all-day basis, 10 percent in the AM peak and 12 percent in the PM peak. The extension would generate a total of up to 260 new transit trips per day and a shift of approximately 150 trips per day from rail transit, for a net increase in revenue of only $54 per day. The additional cost of providing the service would be $395 per day, for a net increase in MBTA operating costs of $341 per day.

Route 64 Extension of this route could result in a relatively large total increase in ridership (670, or a 43 percent over Fall 1984 volumes) but most of the increase (570) would be a shift from other MBTA services. However, much of the service area of Route 64 overlaps that of Route 63. If of the two routes, only Route 64 were extended, it could attract many of the potential trips that otherwise would be made on Route 63 (up to an additional 150 new transit trips, for a total of 250 new trips). This new ridership would also significantly improve the productivity of the route, which is currently one of the lowest performers in the CN area. Without a Route 63 extension, the extension of Route

64 would cost $333 per day and generate $52 a day in new revenue. The net impact on MBTA operating costs would be an increase of $281 per day, which would be the second lowest cost extension that could be implemented. Overall, there would be a slight reduction of bus presence in Central Square (11 to 17 percent), a moderate increase in new transit trips (up to 356 per day), and more convenient service to 570 existing MBTA riders.

Route 70 An extension of Route 70 (all variations to and from Central Square) could result in the largest reduction in bus presence in Central Square (up to 21 percent), but the ridership on the extension would be the second lowest at only 410 per day. Of these, 210 would be new transit riders, 150 would shift from rail transit, and 50 would be current Route 70 riders. On an all-day basis, the cost of extending all route variations from Central Square would be $533 per day, with only $64 in new revenue, for a net cost of $469 per day. However, if a reduction in bus presence is desired in spite of some increased costs, the extension of only peak-period service should be considered. Were this to be done, a large amount of layover time in the most critical periods could be eliminated while the additional cost could be reduced. On this basis, additional net operating costs would be $164 per day.

Route 83 An extension of Route 83 would be well utilized, (up to 1020 trips per day), but most of that ridership (850 trips) would shift from the Red Line. This would occur because even though the Red Line is well utilized by residents and workers in the Route 83 service area, many of them live or work only on the fringes of the Red Line's service area and these trips involve a long walk (more than one-quarter mile) to Red Line stations. As a result, even though the Red Line already provides direct service to Kendall Square, direct service on Route 83 would be more convenient for many people who now walk to the Red Line. This, coupled with the lower bus fare, would cause these people to shift from the Red Line to Route 83. Route 83 accounts for 15 percent of the total layover time spent in Central Square, but 36 percent of the total layover time in the PM peak. Therefore, extension of this route would be most effective in reducing layovers in Central Square in the PM peak.

Lastly, the additional ridership on Route 83 would cause overcrowding during peak periods unless additional service were provided. Therefore, the net impact of this extension, in addition to increasing costs (net costs by at least $570 per day), would be to shift riders from the Red Line, where capacity is already being increased, onto Route 83, where adequate capacity does not currently exist.

Route 91 An extension of Route 91 would have the potential for the largest ridership increase of any of the six routes: from 720 to 1450 additional trips, with up to 1120 being new transit trips. Extension of this route would essentially provide direct service between Kendall/MIT and areas where no direct rail access exists (except at Sullivan Square) and where current bus access requires a transfer to make a relatively short trip. As a result of the current situation, relatively few transit trips are made from the areas served by Route 91 to Kendall/MIT by transit (18 percent), while a much higher than average number of trips are made by private auto than to other Cambridge and Somerville locations, particularly Central Square. One problem with an extension of Route 91 to Kendall Square is that it would provide service to Kendall/MIT indirectly, which could hold ridership below projections. However, much of the new ridership would be to and from MIT, rather than Kendall Square proper, and by nature of the local street network, more direct service would be difficult to provide. As a result, this indirect routing may be the best possible, and may result in the highest increase possible.

The additional passenger loads on Route 91 resulting from the extension would require one additional round trip during both the AM and PM peaks. Including this extra service, the cost of this extension would be $585 per day, up to $404 of which would be offset by new revenue, for a net cost of as low as $181 per day.

2.2 New Service from Somerville and Medford

The routing of any additional service between Central and East Somerville and the Kendall/MIT area, for the most part, would be governed by the alignment of the few cross-town streets wide enough for bus service and the location of suitable terminal points. Most major arterials in Cambridge and Somerville run in an east-west direction or north-south for only a limited distance, while most north-south streets are narrow collector or local roads. As a result, bus service would have to operate on these relatively narrow cross-town streets for much of any route on most possible alignments.

A second consideration in the design of new service in this area would be the location of the outer terminal. Since rail

transit stations are traditionally effective terminal locations, two obvious possibilities for the outer terminal would be the Sullivan Square and Wellington Orange Line stations. Beyond these two stations, the choice of potential terminal locations becomes more limited. However, based upon 1980 Census journey-to-work data, Medford Square also generates and attracts a significant number of trips between Cambridge and Somerville, and therefore could also act as an effective terminal location. By combining these three potential terminal locations with available crosstown street routings to and from Kendall Square, the following four alternatives were developed (see Figure A-1):

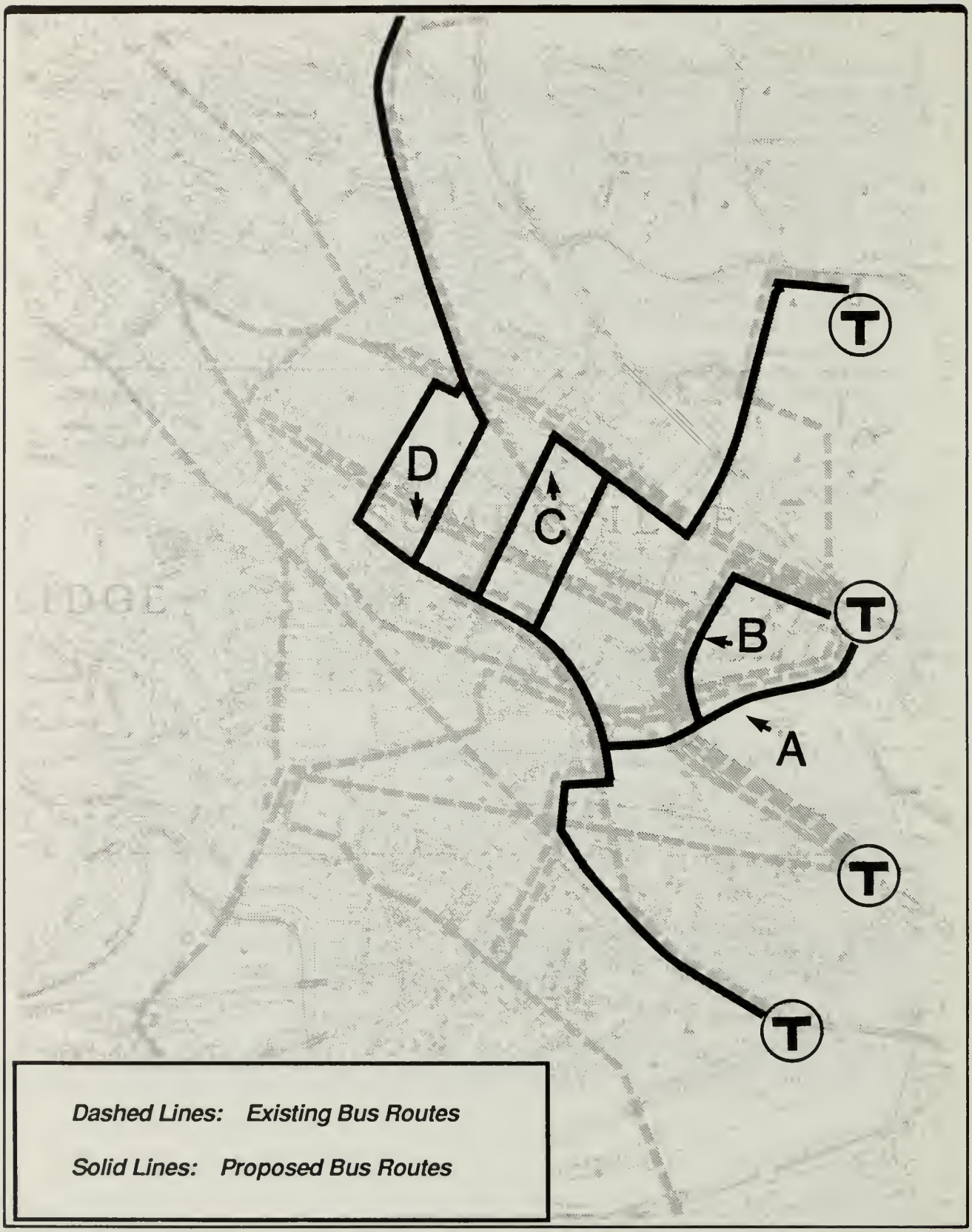
Route A: Kendall Square - Sullivan: via Inman Square, Union Square; between Union Square and Sullivan via Washington St.

Route B: Kendall Square - Sullivan: via Inman Square, Union Square; between Union Square and Sullivan via Cross and Broadway.

Route C: Kendall Square - Wellington: via Inman Square, Union Square; between Union Square and Wellington via Summer, Central (outbound)/School (inbound), Broadway, McGrath O'Brien Hwy, Revere Beach Parkway. Since half of this route would duplicate most of the service provided by Route 85, it was assumed that if this were to be implemented, it would replace the current Route 85.

Route D: Kendall Square - Medford Square: via Inman Square, Union Square; between Union Square and Medford Square via Summer, Lowell (outbound)/Broadway & Cedar (inbound), Medford/Main. As with Route C, much of the alignment of this route would duplicate most of the service provided by Route 85, and it was assumed that this route could replace Route 85.

Potential Ridership on New Routes To estimate ridership on each of the new routes, ridership and service characteristics of the other CN routes operating in Cambridge and Somerville (Routes 69, 83, 85, 86, and 91) were applied to the potential transit markets within the "corridor" served by each of the four alternative alignments. In doing so, a number of different assumptions were tested that resulted in three estimates: the lowest likely ridership, a mid-range value,



Central North Bus	ADDITIONAL SERVICE TO KENDALL SQ.	CTPS
Central/Kendall Analysis	Routes A, B, C, & D	FIGURE A-1

and the highest potential ridership.[6] The resulting estimates are as follows:

TABLE A-9
Estimated Ridership on Routes A, B, C, & D

	Route A	Route B	Route C	Route D
Low Estimate				
New Ridership	70	130	110	130
Shift from Other Transit	540	530	840	1410
Total Ridership	610	660	950	1540
Mid-Range Estimate				
New Ridership	**530**	**680**	**670**	**1010**
Shift from Other Transit	**1070**	**1040**	**1310**	**2200**
Total Ridership	**1590**	**1720**	**1980**	**3210**
High Estimate				
New Ridership	1060	1260	1690	2610
Shift from Other Transit	1220	1190	1890	3170
Total Ridership	2280	2460	3570	5780

[6]In summary, the total potential internal transit market for each alignment was estimated as the number of existing (1980) work trips within each corridor that could be better served by the new route than by any other existing transit services. The following characteristics of existing routes were then applied: Low Estimate: Uses the lowest values for percentage of external trips and non-work trips found on other CN Cambridge/Somerville routes (36 percent and 32 percent, respectively, both from Route 85) and assumes that the transit mode split within the corridor would increase to only 15 percent (from a 1980 level of 12.1 percent to 13.7 percent, depending upon the corridor). Mid-Range: Uses the values for percent of external trips and non-work trips from other CN Cambridge/Somerville routes judged most appropriate for each of the proposed routes, and assumes the new service would result in an increase in the transit mode split in the corridor to 20%. Alignments A and B use external trip and non-work trips percentages from Route 91 (62 percent and 42 percent, respectively), and alignments C and D use external trip and non-work trips figures from Route 86 (at 52 percent and 42 percent). High Estimate: Calculated in the same manner as was the low estimate, except the the highest, rather than the lowest, values of percentage of external and non-work trips from other CN routes in Cambridge and Somerville routes were used (62 percent and 49 percent, respectively; both from Route 69). It also assumes an increase in the transit mode split to 25 percent, which is similar to that along Route 86.

On the basis of overall ridership, Route D would experience the highest ridership of the possible routes (using mid-range estimates, at 3210 trips per day). At this level, and in the Central North area, ridership would be comparable to that of Routes 69 and 86, and higher than on Routes 60, 63, 64, 65, 85, and 91. Ridership on Routes A, B, and C, at 1590, 1720 and 1980 riders per day, respectively, would be among the lower level of CN routes in terms of ridership, at approximately the same level as Routes 64 and 65, and higher than only Route 85.

Further, in the case of Routes A and B, although much of the same market would be served as by an extension of Route 91 from Central Square to Kendall Square, ridership would be much lower on Routes A and B at 500 to 700 new transit riders, compared to 1120 new transit riders on Route 91. The reason for the large difference is that Route 91, using an alignment along Mass Ave. and Vassar St. to Kendall Square, would serve essentially all of the MIT campus, while Routes A and B would only serve the northern half of the campus.[7] Routes A and B could be "extended" from Kendall Square to MIT; however, the routing that would result would be as indirect as would an extension of Route 91 from Central Square, but the cost would be higher.

Productivity of New Routes A, B, C and D Since ridership projections relate the performance of new routes to the performance characteristics of existing routes, implicit in these estimates is the assumption that new routes would have a level of service similar to the existing routes to which they have been compared. On this basis, the minimum levels of service would be as follows:

TABLE A-10
Minimum Levels of Service Assumed in Ridership Projections
(One-Way Trips/Day)

	Route A	Route B	Route C	Route D
Low Estimate	40	40	40	40
Mid-Range Estimate	**110**	**110**	**92**	**92**
High Estimate	119	119	119	119

[7]Based on MAPC estimates, in spite of new construction in the Kendall Square area, most employement remains in the MIT area (census tract 3531). Ridership estimates for the extension of Route 91 assume that all of census tract 3531 would be served, while estimates for Routes A and B assume that only 50 percent of the tract would be served.

In the case of the low estimate, the minimum level of service would be 40 one-way trips per day, as on Route 85. However, this level of service is extremely low compared to that provided on other routes in the area, with service at 30 minute headways in the peak periods and 40 minutes during the mid-day. If a slightly higher level of service were provided, such as that on Route 64, with 20 minute headways in the peak period and 30 minutes during mid-day, about 70 trips per day would be provided. Since this level of service would be more in line with service on other CN routes and more attractive to potential riders, this level has been used instead. For the mid-range and high estimates, the minimum service levels as shown above were used. On this basis, and assuming an average operating speed of 10 mph, passengers per VSM, per VSH, and per trip figures are estimated as shown below in Table A-11.

TABLE A-11
Performance of Routes A, B, C, & D

	Route A	Route B	Route C	Route D
Passenger/VSH				
Low Estimate	31.0	29.2	30.9	46.8
Mid-Range Estimate	**51.7**	**48.7**	**48.9**	**74.2**
High Estimate	68.5	64.6	68.2	103.4
Passenger/VSM				
Low Estimate	3.1	2.9	3.1	4.7
Mid-Range Estimate	**5.2**	**4.9**	**4.9**	**7.4**
High Estimate	6.9	6.5	6.8	10.3
Passenger/Trip				
Low Estimate	8.7	9.4	13.6	22.0
Mid-Range Estimate	**14.5**	**15.6**	**21.5**	**34.9**
High Estimate	19.2	20.7	30.0	48.6

When performance is based on the amount of service provided (Passengers/VSH and VSM), the performance of Routes A, B and C would be similar, while that of Route D would be significantly higher. However, using the mid-range estimates, the performance Routes A, B, and C would be below average for the CN area in terms of passengers/VSH (CN average: 71.7), and all routes would be below average in terms of passengers/VSM (CN average: 8.5).

Financial Performance of Routes A, B, C, & D Based upon the service characteristics determined above, and the projected ridership on each route, the financial performance of each route would be as shown below.

TABLE A-12
Financial Performance of Routes A, B, C, D[8,9]
(Based on Mid-Range Estimate)

	Route A	Route B	Route C	Route D
Daily Operating Cost	$1,411	$1599	$1849	$2006
Daily Ridership	1594	1716	1980	3207
Farebox Revenue	$606	$652	$753	$1219
Farebox Return	42.9%	40.8%	40.7%	60.8%
Net Operating Cost	$805	$947	$1096	$787
Subsidy/Pass.	$0.51	$0.55	$0.38	$0.25

In terms of the financial statistics shown above, (which do not include the financial impact on other routes that would lose ridership), Route D would perform at a higher level than would Routes A, B and C. For Routes A, B, and C, although the ridership would be higher on Routes B and C than on Route A, farebox return and operating cost figures would be better on Route A because of its shorter alignment (approximately 3.0 miles vs. 3.4 and 4.7 miles). In the case of Route D, higher costs associated with a longer route alignment (5.1 miles) would be offset by higher farebox revenues (due to higher ridership), resulting in a route which, considered alone, would be the least costly of the four to operate.

However, when ridership losses from other routes are considered, the difference between the cost of Route D and the others becomes less significant. As previously discussed, much of the ridership on any of the four new routes would be made up of current transit riders that would shift from other transit services (bus and rail) to the new route. For Routes A and B, it can be presumed with a fair degree of certainty that riders would shift from Routes 85, 86 and 91, since the new routes would serve much of the same direct service areas, and that the total shift from these routes could be as high as 1100 riders per day. As of the Fall of 1984, the combined ridership on Routes 85, 86 and 91

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[8]Estimates based on mid-range ridership figures and the same operating cost and average fare figures used in the section on Central Square service.

[9]Figures do not include impact of revenue loss or reduced service on other routes due to shift in ridership to new route.

was 6050 riders per day, so that the combined ridership decrease on these three routes resulting from the implementation of Route A or B could be as high as 18 percent. However, considering the reductions in level of service that have been implemented on Routes 86 and 91 since 1984, and the already low level of service on Route 85, it is unlikely that further reductions could be made as a result of a shift of ridership from those routes.

With respect to the shift in transit riders to Routes C and D, it is less apparent as to which routes riders would shift from. Rather than a shift from a small number of other routes as with Routes A and B, it is more probable that riders would shift from a large number of the different routes currently operating in the two cities, including Routes 80, 85, 87, 88, 89, 90, 91 and 101. As a result, although the ridership shift to Route C or D would be higher than from Route A or B (at up to 1400 on Route C and 2200 on Route D), the number of routes from which these riders would come is large enough so that the ridership loss on individual routes cannot be accurately predicted within the scope of this analysis. However, with Routes C and D, the southern segments of the alignments of both routes closely parallel that of Route 85 to the extent that Route 85 could be replaced by the new route. When these factors are considered, the total net impact on MBTA operating costs for each of the new routes would be as shown in Table A-13. As this table shows, there would be very little difference between the relative net costs for implementation of any of the four alternative routes:

TABLE A-13
Implementation of New Routes - Impact on MBTA Operating Costs
(Daily Costs; Based on Mid-Range Estimate)

	Route A	Route B	Route C	Route D
Operating Cost	+$1411	+$1599	+$1849	+$2006
New Transit Revenue	-$200	-$258	-$256	-$384
Discontinue Route 85	———	———	-$404	-$404
NET IMPACT ON MBTA OPERATING COSTS	**+$1211**	**+$1341**	**+$1189**	**+$1218**

2.3 Extension of Route 69 from Lechmere to Kendall Square

An extension of Route 69 from Lechmere to Kendall Square could link Kendall Square and part of the MIT campus to areas of Cambridge and Somerville on either side of Cambridge St. These areas are currently connected only through a transfer to Route 85, which has a very low level of service (30 minutes peak; 40 minutes off-peak) or by making two transfers

on other services. For the purposes of this examination, a routing back from Lechmere Station along Cambridge St. to Third St. to Kendall Station is assumed.

Using essentially the same procedure to determine ridership as for Routes A, B, C and D, projected ridership would be 208 trips per day. Of these 208 trips, approximately 46 (or 22 percent) would be new transit trips. Based upon an average operating speed of 10 mph combined with an estimated length of the extension of 0.9 miles, boarding and financial data would then be as follows:

TABLE A-14
Performance of Route 69 - Extension Segment

Daily Operating Cost	$458
Daily Ridership	210
(New Ridership)	46
Farebox Revenue	$79
(New Transit Revenue)	$17
Boardings Performance	
Pass./VSH	19.4
Pass./VSM	1.9
Pass/Trip	1.7
Financial Performance	
Farebox Return	17.2%
Net Operating Cost	$379
Operating Cost/Pass	$2.20
Operating Cost/New Rider	$9.95

As can be seen from this information, the performance of an extension of Route 69 would be extremely low. In addition, at these levels, this extension would perform at a significantly lower level than would the extension of any of the Central Square routes to Kendall Square.

2.4 Additional Service to Kendall/MIT - Summary of Findings, Overall Impacts

Demand does exist for service between the Kendall/MIT area and East Somerville, Central Somerville, and the part of Medford examined in this analysis. On an all-day basis, the performance of bus service along the alignments examined would likely be of the same order of magnitude as existing Routes 86 and 91 in terms of passengers per vehicle service hour, and slightly lower in terms of passengers per vehicle service mile. The performance of all four routes would be below average for the Central North corridor, but even based

upon the low range estimates, would be above MBTA minimum service standards.

A summary of the overall impacts of implementation of each alternative examined is as follows:

Route A The implementation of Route A would provide service between Kendall Square and Sullivan Station via Inman Square, Union Square and Washington St. This alignment would serve much of the same market as would an extension of Route 91 from Central Square to Kendall Square but with two differences: (1) less of the MIT area campus would be served, and (2) the routing to Kendall Square would be more direct. Based upon the mid-range estimate, ridership on the route is projected at 1600 trips per day, with about 500 of these trips being made by new transit riders. By comparison, an extension of Route 91 would attract up to 1100 new riders, with the lower ridership increase on Route A due to less of the MIT campus being served. (Were Route A to be "extended" from Kendall Square to serve more of the MIT campus, ridership figures for the two routes would be similar.) The net operating cost of Route A (at 110 trips per day) would be $1211 per weekday, as compared to $184 per weekday for an extension of Route 91.

Route B Route B would serve essentially the same market as would Route A, but would travel between McGrath O'Brien Highway and Sullivan Station along Cross to Broadway, which would provide greater coverage to residential areas in East Somerville. As with Route A, this route would serve much of the same market as would an extension of Route 91 to Kendall Square, but at higher cost and with lower ridership (again, because less of the MIT campus would be served). Ridership would be slightly higher than on Route A (at 1700 per day), with approximately 700 of these trips being made by new transit riders. The net cost of operating this route at 110 trips per day would be $1341 per weekday.

Route C Route C would provide service between Kendall Square and Wellington Station via Inman Square, Union Square, City Hall and Ten Hills. This route would serve essentially all of the market currently served by Route 85 with a higher level of service plus provide extended service to Wellington which would serve much of Central Somerville. Based upon the mid-range estimate, this route would attract 2000 passenger trips per day with a level of service at 92 one-way bus trips per day. Assuming Route 85 would be replaced by this route, the net cost of operating this route would be $1189 per day.

Route D Route D would operate between Kendall Square and Medford Square via Inman Square, Union Square, Summer Street, Lowell Street and Main Street. As with Route C, this route would also serve essentially all of the market now served by Route 85 but at a higher level of service (92 trips per day assumed). This route would have the highest ridership of the four routes at 3,200 per day (based upon the mid-range estimate), with 1,000 of the trips made by new transit riders. Assuming that this route would replace Route 85, the net increase in operating costs would be $1,218 per day.

Extension of Route 69 The extension would serve a very small market (208 riders per day), at a relatively high cost ($408 per day). This extension would perform at a significantly lower level than any of the extensions of Central Square routes.

3.0 REDUCTION OF BUS PRESENCE IN CENTRAL SQUARE

In addition to the extension of Central Square routes to Kendall Square discussed in Section 2.1, a number of other measures could reduce the number of buses laying over in Central Square, or reduce the amount of time spent by buses laying over in Central Square. These are as follows:

- Re-route existing Central Square routes away from Central Square to Kendall Square.
- Combine routes that terminate in Central Square into single routes operating through Central Square.
- Implement through-routing on routes that currently terminate in Central Square during certain time periods.
- Reduce or eliminate layover time on specific routes in Central Square.

Other measures such as the elimination of certain routes, or reduction in the level of service could also reduce bus presence in Central Square. However, since the existing routes all perform relatively well, neither the elimination of routes nor significant reductions in levels of service were considered as serious possibilities. (Although some "fine tuning" with respect to level of service was considered elsewhere.)[10]

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[10]CTPS Memorandum "Bus Route Productivity, Efficiency and Reliability," K. H. Quackenbush, January 28, 1987.

In addition, the option to re-route one or more of the existing Central Square routes away from Central Square to Kendall Square was also eliminated. An examination of transfer patterns of existing riders and of access/egress modes of riders boarding and alighting at Central Square showed that a significant number of riders on these routes use them to travel to Central Square proper and would be seriously inconvenienced by such a change. Further, the routes with the lowest percentage of transfers to other buses in Central Square or trips to Central Square proper are Routes 63, 64 and 70. For each of these routes, the most rational alignment to Kendall Square from Allston would be through Central Square, in which case the alternative would be treated as an extension. No practical alignments exist that could bypass Central Square, even if this were desirable.

3.1 Reduction of Layover Time at Central Square

A fairly simple method of reducing bus presence in Central Square would be to reduce layover time at the Central Square end of a route. Although, this was examined in the 1983 study, many of the schedules have been changed since that time.

Of the two components of layover time (1) recovery time, and (2) additional layover time scheduled so that a route will operate on "clock" headways, or at other specific intervals, reductions can be made in the second without affecting reliability. This section focuses on possible adjustments in this area.

To achieve at least 90 percent[11] on-time performance, recovery time between trips would be set at 1.5 times the standard deviation of the mean running time of trips in the opposite direction in the same time period. On this basis, the amount of layover time included in Fall 1986 schedules was compared to the minimum required recovery time, calculated as described above. A summary of this comparison is included in Table A-15, with extreme values highlighted. (Extreme values were considered to be those where average layover time exceeded the minimum required recovery time by five minutes or more, or where average layover time was greater than two minutes less than the minimum needed to maintain reliable service.)

Most service to and from Central Square is already scheduled so as to minimize the amount of layover time spent in Central Square. On Routes 47, 63, 64 and 70, there are a number of time periods in which layovers could be reduced further. However, on

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[11] The 90 percent on-time figure is used based on recent work at the MBTA. See MBTA Memorandum, "A Proposal for Work in the Scheduling Area," Nigel Wilson, November 15, 1985.

TABLE A-15
CENTRAL SQUARE LAYOVER STATISTICS
FALL 1986

	Early AM	AM Peak	Mid-day	School Peak	PM Peak	Early Evening	Night	All Day
Route 47.0								
Observed Layover (min)	7	8	9	6	*3*	2	6	
(No. of Observations)	(4)	(6)	(17)	(9)	*(7)*	(4)	(8)	
Min Recovery Time (min)	3	4	4	6	*10*	3	7	
Layovers/Time Period	2	6	16	7	*6*	5	9	51
Total Layover Time (min)	14	48	144	42	*18*	10	54	330
Route 63.0								
Observed Layover (min)	4	5	9	3	*2*	3		
(No. of Observations)	(1)	(6)	(9)	(4)	*(6)*	(4)		
Min Recovery Time (min)	NA	5	3	2	*7*	3		
Layovers/Time Period	2	6	11	4	*6*	2		31
Total Layover Time (min)	8	30	98	12	*12*	6		166
Route 63.1								
Observed Layover (min)							7	
(No. of Observations)							(6)	
Min Recovery Time (min)							4	
Layovers/Time Period							5	5
Total Layover Time (min)							35	35
Route 64.5								
Observed Layover (min)	4	7	12	9	4	11		
(No. of Observations)	(1)	(6)	(8)	(4)	(6)	(5)		
Min Recovery Time (min)	NA	5	4	2	6	5		
Layovers/Time Period	3	6	11	4	6	3		33
Total Layover Time (min)	12	42	127	36	24	33		274
Route 70 (all)								
Observed Layover (min)	11	10	11	*6*	*0*	14	12	
(No. of Observations)	(2)	(12)	(11)	*(8)*	*(9)*	(9)	(4)	
Min Recovery Time (min)	6	5	6	*9*	*15*	4	6*	
Layovers/Time Period	3	7	10	*5*	*8*	5	5	43
Total Layover Time (min)	32	70	105	*30*	*0*	70	60	367
Route 83.1								
Observed Layover (min)	2	*2*	9	7	7	7	*0*	
(No. of Observations)	(2)	*(5)*	(8)	(6)	(9)	(5)	*(5)*	
Min Recovery Time (min)	4	*9*	8	6	3	3	*9**	
Layovers/Time Period	4	*9*	11	6	8	4	*6*	48
Total Layover Time (min)	8	*22*	99	42	56	28	*0*	255
Route 91.0								
Observed Layover (min)	3	8	8	6	9	*1*	2	
(No. of Observations)	(1)	(8)	(20)	(10)	(7)	*(4)*	(5)	
Min Recovery Time (min)	NA	4	4	5	6	*5*	3	
Layovers/Time Period	3	5	12	5	5	*3*	5	38
Total Layover Time (min)	9	40	96	30	45	*3*	10	233
TOTALS								
Layovers/Time Period	17	39	71	31	39	22	30	249
Total Layover Time (min)	83	252	669	192	155	150	159	1660
Avg No. of Buses Laying Over in C.Sq at Any Given Time:		2.1	2.1	1.6	1.3	1.3		

* Rt 70 and Rt 83 night services are interlined. Minimum Recovery Time is therefore based on the STD of mean running times on the incoming route (i.e., Route 70 in for Route 83 outbound recovery times and vice versa for Route 70 outbound service).

Key: = Surplus Recovery Time (Actual Recovery Time exceeds Minimum Req'd by >= 5 mins.)

= Insufficient Recovery Time (Observed Recovery Time > 2 mins less than Minimum Req'd.)

Routes 47, 63, 70, 83 and 91, there are also time periods in which recovery time is so low that on-time performance is affected. In these cases, if 90 percent on-time performance were to be provided, recovery time would have to be increased.

In order to maintain existing clock headways, schedules could only be adjusted in five minute increments (either forward or backwards). If this were to be done in all instances in which surplus or insufficient recovery time existed as shown in Table A-16, layover statistics would become as shown in Table A-17. The net impact of both types of changes would be very little difference in the total amount of layover time spent in Central Square, but a worsening of conditions during peak periods, and an improvement during most off-peak periods. This is displayed below in Table A-18 in terms of the total layover time per time period (in minutes) and the average number of buses laying over in Central Square during each time period:

TABLE A-18
Impact of Adjusting Layover Times to Minimize Layover Time in Central Square While Achieving 90% On-Time Performance

	Early Morn	AM Peak	Mid-day	School Peak	PM Peak	Early Eve.	Night	All Day
Minutes of Layover Time								
Fall 1986	83	245	669	192	155	149	159	1652
w/Adjustments	69	303	440	197	365	100	194	1668
% Difference	-17%	+24%	-34%	+3%	+135%	-33%	+22%	0%
Avg. No. of Buses Laying Over in Central Square (at any given time)								
Fall 1986		2.1	2.1	1.6	1.3	1.3		
w/Adjustments		2.5	1.4	1.6	3.0	0.8		

During the AM peak and night periods, the increases are due to the need for additional layover time on Route 83, which are partially offset by a reduction of recovery time on Route 70 during both periods. During the PM peak, additional layover time is needed on Routes 63, 64 and 70, which would result in a 135% increase in bus presence, with the average number of buses laying over at any given time during this period increasing from 1.3 to 3.0. Most of this increase would be due to the need for 15 minutes of recovery time on Route 70. Because of the length of Route 70 (9.3 miles inbound), there are many opportunities for the buses to become delayed, resulting in highly variable running times (mean inbound running time: 51 minutes; STD: 10.3 minutes).

TABLE A-16
LAYOVER TIME ADJUSTMENTS

A. Adjustments to Reduce Layover Time in Central Square (maintain existing cycle-to-run time ratios, but shift portion of layover time from Central Square end of route to other end)

	Observed Run Time (Mean)	Observed Layover (Mean)	Lowest Required @ 90% On-Time Perf	Reduction Possible
Route 47.0				
Mid-day	31	9	4	5
Route 63.0				
Mid-day	22	9	3	5
Route 64.5				
Mid-day	18	12	4	5
School	21	9	2	5
Evening	26	11	5	5
Route 70.0				
Early AM	32	11	6	5
AM Peak	45	10	5	5
Mid-day	41	11	6	5
Evening	36	14	4	10
Night	38	12	6	5

B. Increases in Layover Times Necessary to Provide 90% On-Time Departure Performance from Central Square:

	Observed Run Time (Mean)	Observed Layover (Mean)	Lowest Required @ 90% On-Time Perf	Increase Required
Route 47.0				
PM Peak	39	3	10	7
Route 63.0				
PM Peak	28	2	7	5
Route 70.0				
School	44	6	9	3
PM Peak	51	0	15	15
Route 83.1				
AM Peak	28	2	9	7
Night	14	0	9	9
Route 91.0				
PM Peak	16	1	5	4

TABLE A-17
CENTRAL SQUARE LAYOVER STATISTICS
IF SCHEDULES WERE ADJUSTED FOR MINIMUM LAYOVER TIME AT 90% RELIABILITY
(BASED ON FALL 1986 SCHEDULE)

	Early AM	AM Peak	Mid-day	School Peak	PM Peak	Early Evening	Night	All Day
Route 47.0								
"Optimum" Layover Time (min)*	7	8	4	6	13	2	6	
Observed Layover Time (min)	7	8	9	6	3	2	6	
Layovers/Time Period	2	6	16	7	6	5	9	51
Total Layover Time (min)**	14	48	64	42	78	10	54	310
% of Total for the Time Period	20.3%	15.8%	14.5%	21.3%	21.4%	10.0%	27.8%	18.6%
Route 63.0								
"Optimum" Layover Time (min)*	NA	5	4	3	7	3		
Observed Layover Time (min)	4	5	9	3	2	3		
Layovers/Time Period	2	6	11	4	6	2		31
Total Layover Time (min)**	8	30	44	12	42	6		142
% of Total for the Time Period	11.6%	9.9%	10.0%	6.1%	11.5%	6.0%		8.5%
Route 63.1								
"Optimum" Layover Time (min)*							7	
Observed Layover Time (min)							7	
Layovers/Time Period							5	5
Total Layover Time (min)**							35	35
% of Total for the Time Period							18.0%	2.1%
Route 64.5								
"Optimum" Layover Time (min)*	NA	7	7	4	4	6		
Observed Layover Time (min)	4	7	12	9	4	11		
Layovers/Time Period	3	6	11	4	6	3		33
Total Layover Time (min)**	12	42	77	16	24	18		189
% of Total for the Time Period	17.4%	13.9%	17.5%	8.1%	6.6%	18.0%		11.3%
Route 70 (all)*								
"Optimum" Layover Time (min)*	6	5	6	11	15	4	7	
Observed Layover Time (min)	11	10	11	6	0	14	12	
Layovers/Time Period	3	7	10	5	8	5	5	43
Total Layover Time (min)**	18	35	60	55	120	20	35	343
% of Total for the Time Period	26.1%	11.6%	13.6%	27.9%	32.9%	20.0%	18.0%	20.6%
Route 83.1*								
"Optimum" Layover Time	NA	12	9	7	7	7	10	
Observed Layover Time	2	2	9	7	7	7	0	
Layovers/Time Period	4	9	11	6	8	4	6	48
Total Layover Time (min)**	8	108	99	42	56	28	60	401
% of Total for the Time Period	11.6%	35.6%	22.5%	21.3%	15.3%	28.0%	30.9%	24.0%
Route 91.0								
"Optimum" Layover Time (min)*	NA	8	8	6	9	6	2	
Observed Layover Time (min)	3	8	8	6	9	1	2	
Layovers/Time Period	3	5	12	5	5	3	5	38
Total Layover Time (min)**	9	40	96	30	45	18	10	248
% of Total for the Time Period	13.0%	13.2%	21.8%	15.2%	12.3%	18.0%	5.2%	14.9%
TOTALS								
Layovers/Time Period	17	39	71	31	39	22	30	249
Total Layover Time (min)**	69	303	440	197	365	100	194	1668
Avg No. of Buses that would Lay Over in C.Sq at Any Given Time:		2.5	1.4	1.6	3.0	0.8		

* "Optimum" Recovery Time refers to the minimum amount of layover time necessary to maintain 90% on-time performance with departures at current (Fall 1986) clock headways.

** Total Layover Time is the Optimum Layover Time times the number of layovers in the time period unless the Optimum Layover Time was not available. In those cases, Observed Layover Time times the number of layovers in the time period was used.

*** Rt 70 and Rt 83 night services are interlined. Layover times are therefore based on the STD of mean running times on the incoming route (i.e., route 70 in for 83 outbound recovery times and vise versa for Rt 70 outbound service).

Considering all of the above, if current operations are maintained, but schedules adjusted to minimize recovery time in Central Square and to provide 90% on-time performance, bus presence would increase rather than decrease during critical periods. In order to avoid this situation, a certain degree of unreliability will have to be tolerated, or other actions must be taken to remove, rather than minimize, layovers in Central Square (such as the extension of routes to Kendall Square).

3.2 Combination or Through-Routing of Routes Currently Terminating in Central Square

One method of removing bus layovers from Central Square would be to combine two routes that currently terminate in Central Square into one longer route operating through Central Square, or to through-route specific routes straight through Central Square without layovers during certain time periods. The combination of two routes would eliminate all layovers in Central Square on both routes throughout the day; through-routing could reduce layovers during certain time periods.

In the Central Square area, any one route could be matched with another simply in terms of level of service, which would be necessary in order to avoid significantly increasing or decreasing service on one of the routes being combined (Route 63.0 with Route 64.5, and any combination of Routes 47.0, 70 (all variations combined), 83.1 and 91.0). However, most of these routes also experience a high degree of running time variability during critical periods (AM or PM Peaks), which would mean that any combinations of these routes would result in less reliable service out of Central Square. Based upon the variability of trip times observed on trips operating into Central Square, the percentage of trips that would leave Central Square either early or late can be predicted as follows:

TABLE A-19
Percentage of Late Departures from Central Square that would Result from Route Combinations[11]

	% of Trips > 3 Min Early or Late	% of Trips > 5 Min Early or Late
AM Peak		
Route 47.0 Segment	27%	6%
Route 63.0 Segment	35%	12%
Route 64.5 Segment	43%	19%
Route 70.0 Segment	38%	14%
Route 83.1 Segment	62%	41%
Route 91.0 Segment	30%	9%
PM Peak		
Route 47.0 Segment	65%	45%
Route 63.0 Segment	53%	30%
Route 64.5 Segment	48%	25%
Route 70.0 Segment	77%	63%
Route 83.1 Segment	17%	2%
Route 91.0 Segment	44%	19%

As can be seen from this table, a significant number of trips on all Central Square routes would arrive in Central Square more than 3 minutes early or late. As of Fall 1984, very few trips left early, and no more than two departures were observed more than 3 minutes late during peak periods for any Central Square route. This means that in all cases, the elimination of layovers in Central Square that could be caused by combining or through routing existing routes would also cause a significant degradation of on-time performance from Central Square.

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[11]The segments listed in this table would be the first segment of a combined route, with the second segment, no matter which other route were involved, experiencing late departures as shown.

APPENDIX J
SOMERVILLE/CAMBRIDGE CROSS-TOWN ROUTES

CTPS

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CENTRAL TRANSPORTATION PLANNING STAFF

MEMORANDUM

TO: Central North Bus Study Files October 30, 1987

FROM: Karl H. Quackenbush

RE: Somerville/Cambridge Cross-town Routes

1 Introduction

Somerville officials have, from time-to-time, expressed an interest in the MBTA starting a new cross-town bus route linking Somerville to Cambridge.[1] CTPS was asked to examine the feasibility of such a route and this memorandum documents the findings. The memorandum begins with brief descriptions of the current bus network and a past cross-town service experiment in Somerville. Problems in providing cross-town service are listed and alternative route alignments chosen for the analysis are described. Estimates of patronage and performance for these alternatives are presented, and finally, recommended actions are presented at the end.

2 Current Bus Routes

Most MBTA bus routes in Somerville are radially oriented. They traverse the city from the northwest to the southeast, terminating at Lechmere or Sullivan Station. Four routes provide limited cross-town service. Route 96 traverses the northwest part of Somerville in a cross-town direction between Medford and Cambridge, and Routes 86 and 91 operate in a cross-town fashion in East Somerville between Sullivan Station and Cambridge. Route 90, which connects Wellington, Sullivan and Davis Stations, is somewhat cross-town in nature as it operates between Wellington and Sullivan, but clearly radial between Sullivan and Davis.

Somerville lacks a truly cross-town route that connects activity centers in the heart of Somerville to a major Cambridge activity center such as Harvard or Porter Square, and it is such a route that Somerville officials have been interested in.

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[1] Such an interest was formally expressed, for example, in a May 31, 1985, meeting between MBTA Service Planning officials and the Somerville Director of Community Development.

3 Past Cross-town Service

In 1973, the MBTA instituted a mini-bus program. One of the mini-bus routes served Somerville and operated between Temple Street/Mystic Avenue in the Ten Hills section and Gordon Street/Mystic Valley Parkway in the northwest section of the city. Figure 1 shows the route that this mini-bus took. The route connected such activity centers as the city hall/high school area, Somerville Hospital and Davis and Teele Squares. It was operated with two vehicles running on 30-minute headways.

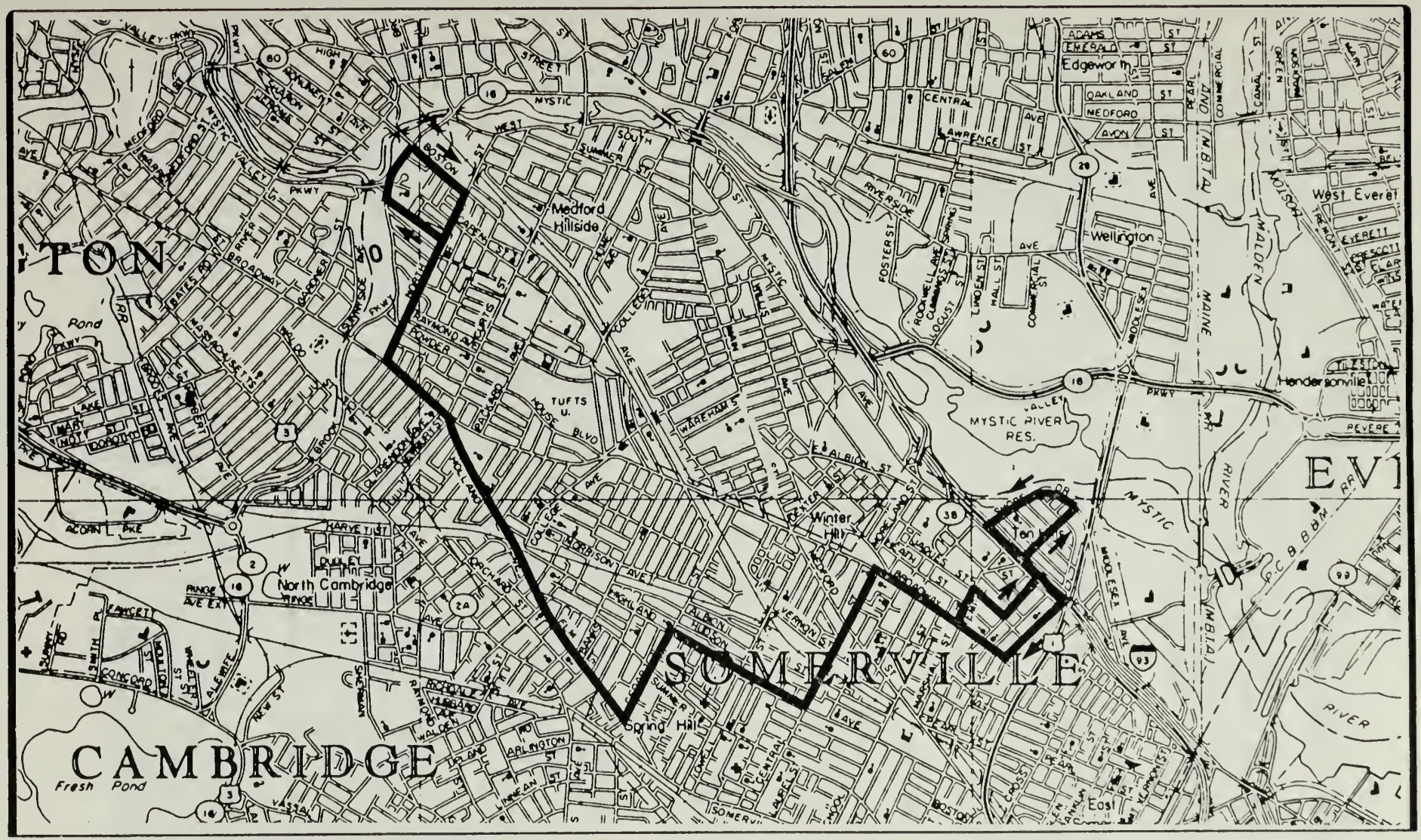
Although the mini-buses demonstrated an advantage over standard 40-foot buses on Somerville's narrow and hilly streets, the route was discontinued in the Spring of 1981. Most of the other mini-bus routes were also discontinued around that time. The vehicles had proven to be more difficult and expensive to maintain than expected and due to driver costs being the largest component of operating costs, expected savings compared to running full sized buses were not realized. In addition, the routes were not well patronized.

There are some advantages that a regular cross-town route, of the type discussed herein, would have over the mini-bus route. First, it would connect with rapid transit stations at both ends and a significant retail activity center at one end, providing potential trip generating capability that the mini-bus route lacked. Second, operating costs, due to the use of regular 40-foot buses, would be predictable and in line with the fleet as a whole. Third, regular buses running on a regular route might have more visibility than the mini-buses did and might thereby generate more riders.

4 Obstacles to Provision of Cross-town Service

There are several problems associated with providing regular cross-town bus service through Somerville. Whether they would prevent a cross-town route from being instituted on particular streets would have to be assessed by MBTA personnel. The observations made below are from CTPS field surveys and are not meant to be definitive.

Effective road widths at certain points along some cross-town arterials, given the amount of on-street parking that exists, are barely sufficient for the safe passage of buses under the best circumstances. When snow accumulation constricts these streets, bus passage would be even more



SOMERVILLE MINIBUS
ROUTE (ROUTE 590)

Technical Memorandum
KHQ 10-30-87

CTPS
FIGURE
1

difficult. The narrowest effective street widths noted in field observations are the following:

- o School Street: the two-way portion between Broadway and Medford Streets.
- o Central Street: between Highland Avenue and the railroad tracks, and just north of Medford Street.

Somerville is known for its hills and some cross-town streets have grades as great as 11 or 12 percent for short durations. Although the MBTA has no fixed rule governing maximum grades for route alignments, sharp grades certainly detract from the desirability of some streets as bus routes. The following, calculated from a U.S.G.S map, are sample grades on three major cross-town streets:

Street	Grade	Location
School	7.0%	Just south of Highland
	11.0%	Just north of Highland
Central	7.5%	Just south of Summer
	8.8%	Just north of Medford
Lowell	7.2%	Between Somerville and Summer
	10.0%	Just north of Brastow
	12.0%	Vicinity of Summer

Due to narrow streets and on-street parking, some turns would be difficult for buses to accomplish. In some cases, particular routings would be ruled out altogether and in others, parking restrictions right at an intersection would be necessary. Route 85, as it loops through residential Spring Hill, makes turns similar to those that would confront a cross-town route.

The one-way street system in Somerville rules out certain portions of some cross-town streets, such as School or Lowell, for two-way bus routing. Although one-way streets are often easier for buses to traverse due to their greater effective widths and lack of conflicts from reverse traffic, the need to use one-way street pairs may complicate routing logistics.

Maximum bridge weight limits occasionally rule out a street as a bus route, but this was observed to be a definite problem only in the vicinity of Porter Square. Some bridges there have maximum limits of six tons, a few tons short of what would be required for bus traffic. The major cross-town

street bridges in Somerville, however, are rated at 14 tons, about what some makes of loaded buses would require.

A final possible constraint to a cross-town route is that a layover would be difficult to accommodate in Porter or especially Harvard Square. This problem could be lessened by loading all or most of the layover time onto the other end of the route, but on-time performance would then be more difficult to maintain.

In short, the constraints listed represent potentially serious drawbacks to a cross-town route. However, the alignments described in the following section have been chosen with an effort to minimize as many of these problems as possible.

5 Alternative Cross-town Alignments

Four alternative alignments were analyzed: two connect Wellington Station with Porter Square and two connect Wellington with Harvard Square. In addition, an extension of one of the Wellington-to-Porter alignments west into West Cambridge was analyzed.

Several criteria, in addition to the physical constraints listed above, governed the choice of alignments. First, in order to maximize patronage, it was deemed desirable for a route to terminate at a major activity center and/or rail station at both ends. Wellington was chosen as the northeastern terminal for all routings because it is northeast of where any cross-town alignment would probably begin. In addition, Wellington Station experiences a significant parking shortage (its lot is usually full by 8:15), and although most park & riders at the station come from the north, some are from Somerville and might switch to a bus, if provided. For Boston-bound bus-to-rail patrons, Sullivan is more direct than Wellington, but some who care about getting a seat on Orange Line trains in the morning could be attracted to a bus/Orange Line connection at Wellington, as would those who are traveling northbound on the Orange Line. (One's odds of getting a seat at Wellington inbound in the morning are 50/50; at Sullivan, near zero.)

Another criterion in the selection of route alignments was that they, indeed, be cross-town in nature. Route 90, sometimes referred to as a cross-town route, is really only partially so. As much of its mileage is radial, on Highland Avenue, as it is cross-town and the latter portion only serves a part of east Somerville.

Either Porter or Harvard Square was seen as the logical southwestern terminal for a route. Each lies to the

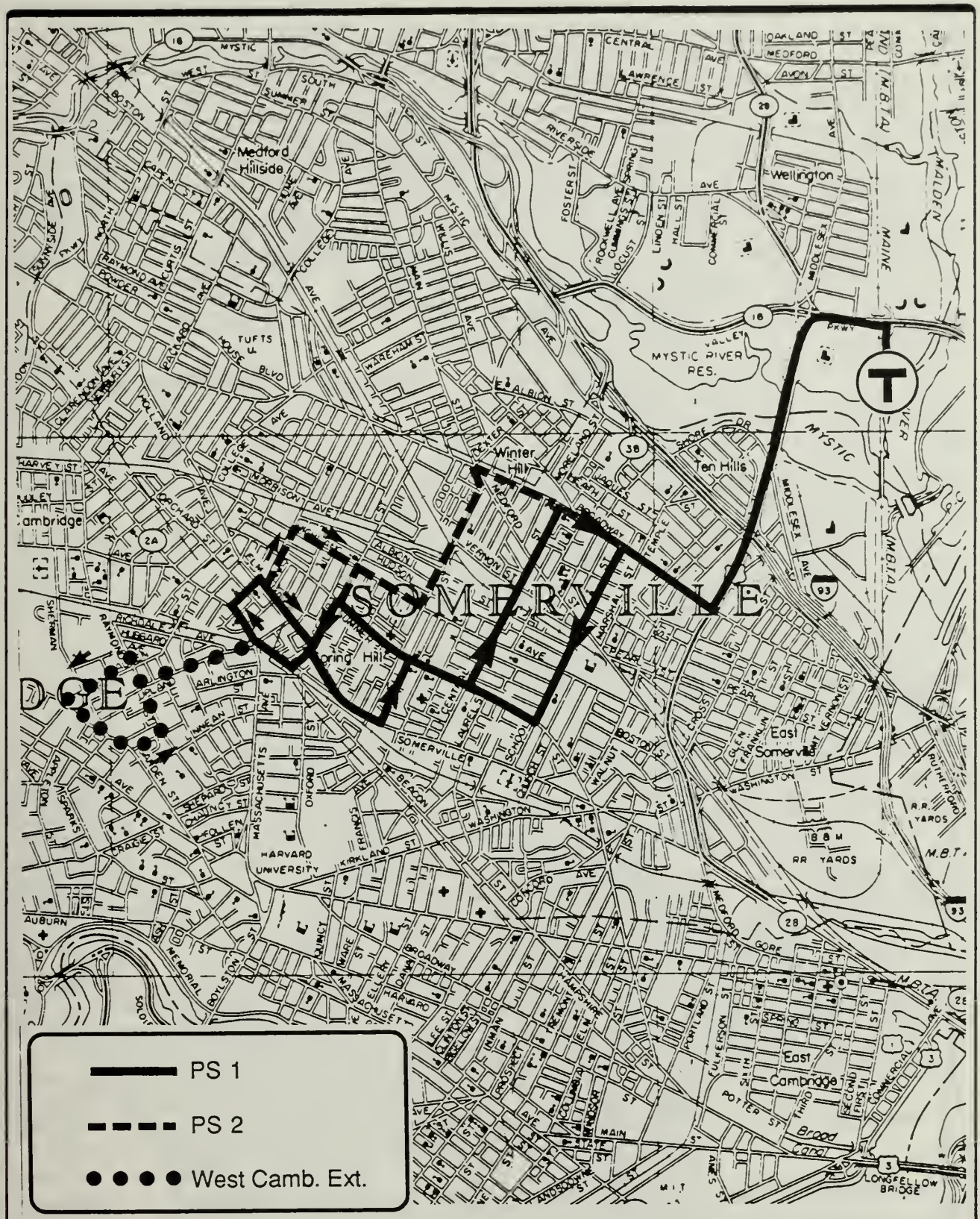
southwest of a cross-town corridor and each is a major activity center in addition to being the site of a rapid transit station. In addition, each currently receives less Somerville bus traffic than either Central Square to the east or Davis Square to the west. (In fact, no bus routes terminate at Porter Square, although a few pass through it.)

Within Somerville itself, it was deemed desirable that a new route traverse the heart of the city and include as many activity centers as possible. A route too far to the west would overlap with Route 96, which provides service into Davis and Harvard Squares. A route too far to the east would overlap with Routes 86, 90 and 91, which provide service into Harvard, Davis and Central Squares respectively. Activity centers located in the city's central neighborhoods that would be served by various of the alternative alignments include the high school/city hall area on Highland Avenue, Magoun Square, Winter Hill and Somerville Hospital.

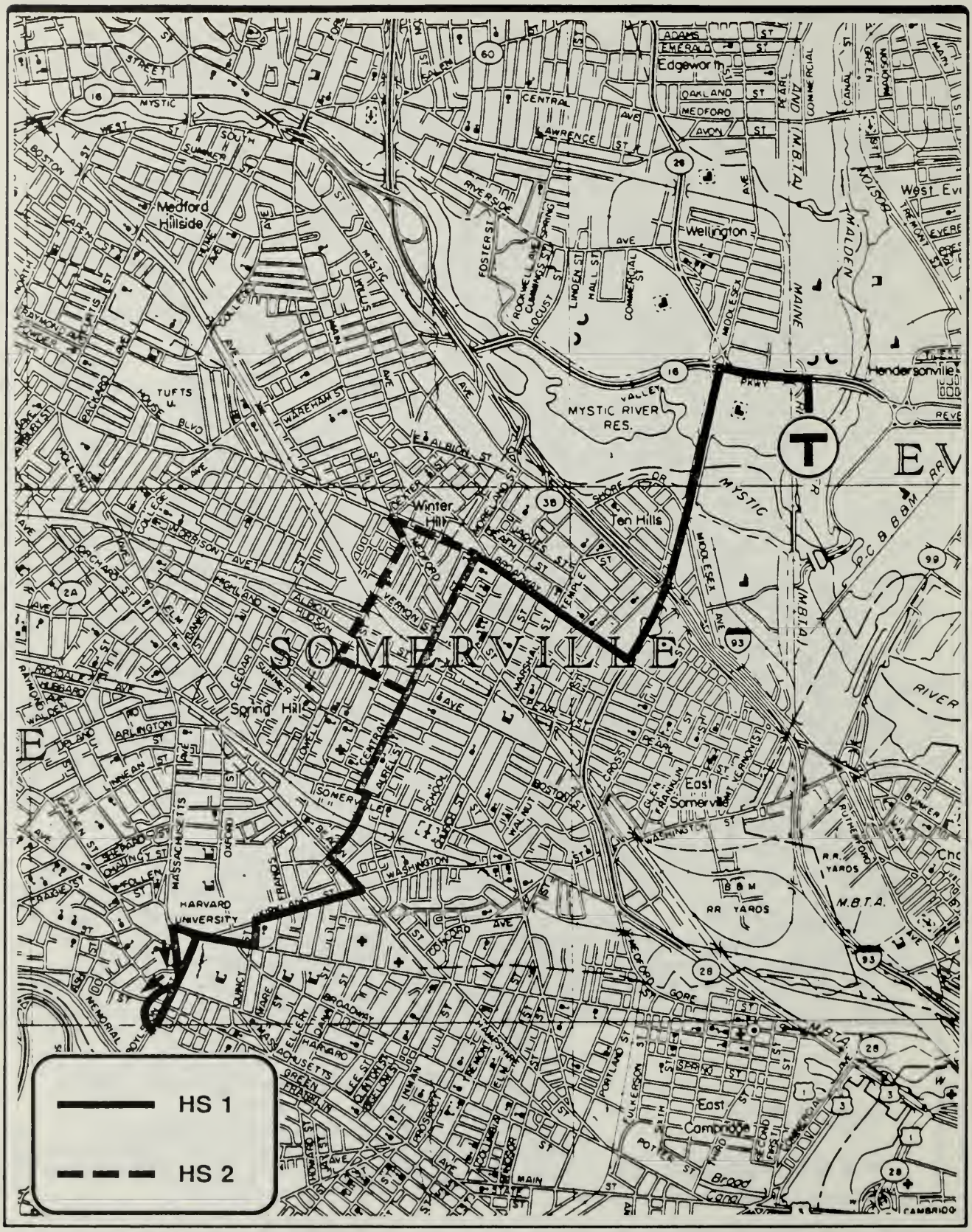
Figures 2 and 3 depict the alignments analyzed. In Figure 2, it can be seen that the Wellington-to-Porter alignment 2 (PS #2) operates further west than the Wellington-to-Porter alignment 1 (PS#1), goes through Magoun Square, but misses city hall. PS #2 avoids the narrow spots of Central and School Streets, but encounters a fairly tight turn from Medford to Lowell Street.

An option for either alignment would be an extension west from Porter Square along Upland Street into West Cambridge. This extension would require buses to loop through Porter Square counterclockwise, the reverse of what is depicted, due to there being a left turn restriction from Somerville Avenue onto Massachusetts Avenue. A major drawback to such an extension is that it would encounter some narrow passages and tight turns. (Upland Street closer to Mass. Avenue is totally unworkable due to a narrow street width and a six-ton weight limit on the railroad bridge.) Also, it traverses a residential area whose residents are unused to having buses on their streets. However, it would provide service to one of the very few pockets in Cambridge and Somerville beyond one-quarter mile of a transit line and it might create a better layover location than Porter Square.

Figure 3 shows that the two Wellington-to-Harvard alignments differ very little from one another. The first (HS #1) traverses the entire length of Central Street while the second (HS #2) deviates further west onto Lowell Street. These are identical to the Porter Square alignments from Broadway north. South of Somerville Avenue, the Harvard Square alignments would traverse Park, Beacon and Kirkland Streets which already have bus traffic.



Central North Bus	WELLINGTON STATION TO PORTER SQUARE ALTERNATIVES	CTPS
Technical Memorandum KHQ 10-30-87		FIGURE 2



Central North Bus	WELLINGTON STATION TO HARVARD SQUARE ALTERNATIVES	CTPS
Technical Memorandum KHQ 10-30-87		FIGURE 3

6 Demand For Cross-town Service

6.1 Potential Latent Demand

Work trips from the 1980 Census, summarized in Table 1, were used to gain a "first cut" impression of the potential market for cross-town transit service. As shown in the table, cross-town work trips to Cambridge make up 13 percent of all Somerville work trips. This represents a small but significant portion of all work trips. In addition, the ten percent of all work trips made within the neighborhood of residence include some short cross-town trips.

All together, 28 percent of Somerville residents use transit to get to work. Forty-three percent of those traveling in a radial direction use transit, but only twenty percent of those traveling cross-town to Cambridge do so. This is not surprising, given that radially-oriented trips are provided with more transit service, and include those made to Boston's CBD where incentives for using transit are strong. Subtracting current transit users, there are 3,800 workers traveling cross-town to Cambridge by non-transit means. In central Somerville alone, there are 2,100 such people.

Work trips from Cambridge to Somerville show a smaller transit mode-share (16 percent) than either those from Somerville to Cambridge or all Cambridge work trips. This relatively low transit mode share does not imply a significant untapped transit market though: only 600 Cambridge workers travel cross-town to Somerville by non-transit means.

In short, the census figures indicate that, when considering Somerville as a whole, and central Somerville specifically, there is a potential untapped market for more cross-town transit service to Cambridge. This market is composed of the known number of work trip-makers who do not now use transit, perhaps because of the inconvenience of current cross-town service, and of an unknown number of people making school or other kinds of cross-town trips by non-transit means. Given that half the people on board buses in the area are making non-work trips, the latter group is conceivably as large as the work trip-makers.[2] Of course, all new transit users would be in addition to those who currently use transit to travel to Cambridge, but who would switch to a more direct route, if provided.

A cross-town route that connected with Wellington Station at one end and Porter or Harvard Station at the other might

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[2] Central North Bus Study on-board survey, conducted by CTPS, January 1985.

From:	To: Cross-town to Cambridge	Radial Direction	Within Same Neighborhood	All Other Destinations	Total	% Cross-town to Cambridge
WEST SOMERVILLE						
all modes	848	5455	915	4434	11652	7%
transit only	*123*	*2230*	*120*	*773*	***3246***	***4%***
transit mode share	15%	41%	13%	17%	28%	
CENTRAL SOMERVILLE						
all modes	2665	6658	2188	5923	17434	15%
transit only	*562*	*2777*	*142*	*1257*	***4738***	***12%***
transit mode share	21%	42%	6%	21%	27%	
EAST SOMERVILLE						
all modes	1216	2557	614	3024	7411	16%
transit only	*277*	*1285*	*41*	*698*	***2301***	***12%***
transit mode share	23%	50%	7%	23%	31%	
TOTAL SOMERVILLE						
all modes	**4729**	**14670**	**3717**	**13381**	**36497**	**13%**
transit only	***962***	***6292***	***303***	***2728***	***10285***	***9%***
transit mode share	**20%**	**43%**	**8%**	**20%**	**28%**	

Source: U.S. Census Journey-to-Work Data

Central North Bus	WORK TRIP DESTINATIONS OF SOMERVILLE RESIDENTS	CTPS
Technical Memorandum KHQ 10-30-87		TABLE 1

also serve some Somerville residents who, because they lack convenient bus access to the rail transit system, are currently traveling to Boston or to park and ride lots by automobile. In reality, this market is probably small, given that most Somerville residents have direct bus service to rail stations.

6.2 Demand Estimates

A judgmental technique was used to estimate the demand for each alternative. (See Attachment A for a complete description of the method.) For each, a matrix of census tract-to-tract internal transit work trips was first produced from Census Journey-to-Work data. For each interchange, the number of these trips produced and attracted within an assumed quarter mile service area of the alternative route was then estimated and the number of these that would be better served, hence captured, by the alternative cross-town route was estimated.

This estimate of internal work trips captured from other bus routes was then factored up, using data from nearby bus routes, to account for internal trips of all purposes captured from other routes. Then, using the rule-of-thumb that two-thirds of a new bus route's patrons are typically those diverted from other transit services, the previous figure was factored up to an estimate of total internal travel demand. Finally, again using data from nearby routes, this figure was factored up to include patronage by people with one or both trip ends external to the half-mile wide cross-town corridor under consideration. Sensitivity analysis was performed on these estimates, and all the results, expressed as weekday boardings, are presented in Table 2.

All of the alternatives analyzed would be among the lower patronized routes in Cambridge and Somerville. In Table 2, the mid-range estimates, those incorporating what are deemed the most likely assumptions, indicate that the Harvard Square alignments would attract roughly 1320 to 1430 weekday passenger trips, over twice as many as the 460 to 610 that the Porter Square alignments would attract. The extension of PS #1 into west Cambridge would generate roughly 120 additional trips.

Table 2

	Wellington - Porter			Wellington - Harvard	
	PS #1 w/ extension	PS #1 no extension	PS #2	HS #1	HS #2
Mid-range	**583**	**459**	**608**	**1316**	**1427**
Lower-bound	387	305	402	945	897
Upper-bound	1089	857	1232	2211	2623

For perspective, projected patronage on PS #1 is equivalent to that on Route 85, Spring Hill to Kendall Square, while patronage on PS #2 would be equivalent to that on Route 90, Wellington to Davis. The ridership on HS #1 and HS #2 would be roughly comparable to that on Route 72, Huron Avenue to Harvard.

6.3 Discussion

The difference in demand between the two Porter alignments is due to a difference in the current number of internal transit work trips being made within each corridor: there are more in PS #2 largely due to its including Magoun Square and part of Davis Square. The difference in demand between the two Harvard Square alignments is also due to differences in the current number of these trips, and this difference is, in turn, partially due to a 0.6 mile difference in route lengths.

The Harvard Square alternatives show a greater potential demand than those into Porter, in part, because there are more current transit work trips made to Harvard than to Porter from central Somerville. Also, the Harvard Square routes are longer (by 20 to 37 percent), and they were projected to capture a higher percentage of the current internal transit work trip-making in their corridors than the Porter routes.

Setting aside the mechanics of the demand estimation method, there are plausible reasons for the relatively low demand for a cross-town route of the type analysed. First, as shown previously, the underlying level of cross-town travel to Cambridge is less than that of radial travel, and some of it is already conveniently served by existing routes. More important, cross-town travelers to Cambridge are spread out. Even in central Somerville through which a route would

pass, a single route would not come close enough to all potential riders to compel them to switch from other modes.

Furthermore, some travelers who would be close to the route would not use it anyway. People traveling cross-town from Somerville to Cambridge are making short trips. A route of the type analysed would present the traveler with a high level of walking and waiting time relative to time spent on the bus.[3] Since out-of-vehicle time is considered by most travelers to be more onerous than in-vehicle time, such a transit trip to Cambridge would be viewed as less attractive relative to competing modes than, say, those made to Boston. In fact, one competing mode - walking - would surely remain more attractive than transit for some: from south central Somerville, one can walk to Harvard Square in 15 minutes. Furthermore, the disincentives for driving an auto to Cambridge may not, for many people, be as strong as those for driving to downtown Boston.

As noted previously, most Boston-bound travelers would have little incentive to switch to a cross-town route, and the previous estimate of such travelers attracted to the route should be considered optimistic. Somerville is already well served by buses that connect to Boston-bound rail lines, and a new route would not be very much more convenient.

7 Performance Estimates

Table 3 shows, along with demand, the estimated costs, revenues and performance measures for the alternative routes. Costs and revenues are based on similar routes in the Cambridge/Somerville area. Also shown in the table are the underlying levels of service assumed for the routes. These are composites of the levels of service on selected existing routes in the study area. They follow from the assumption that the new routes, in order to experience the demand indicated above, would have to have levels of service roughly similar to existing routes from which many of the patrons would be drawn.

The performance measures shown, sensitive as they are to the assumed levels of service, are meant to be approximate. They show that the Harvard routes would perform better than the Porter routes and that all of them would be weak compared to most routes in Somerville and Cambridge.

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[3] A typical cross-town bus rider could conceivably spend 5 minutes walking to the bus, 5 minutes waiting for it and 10 minutes riding it, thus spending 50 percent of his/her time walking and waiting.

	Wellington - Porter			Wellington - Harvard	
	PS #1 w/ extension	PS #1 no extension	PS #2	HS #1	HS #2
Boardings*	583	459	608	1316	1427
Cost**	$1,193	$994	$975	$1,392	$1,568
Revenue***	$221	$174	$231	$500	$542
1-way trips****	60	60	60	70	70
Boardings/Trip	9.7	7.6	10.1	18.8	20.4
Boardings/Mile	2.00	1.91	2.56	3.88	3.74
Boardings/Hour	17.7	16.6	22.5	34.2	32.9
Revenue/Cost	0.19	0.18	0.24	0.36	0.35
Net Cost/Pass.	$1.67	$1.79	$1.22	$0.68	$0.72
Vehicles - headway					
peak	2 - 33	2 - 30	2 - 30	3 - 22	3 - 25
midday	2 - 33	2 - 30	2 - 30	2 - 33	2 - 35
night	1 - 60	1 - 60	1 - 60	1 - 60	1 - 60

* Mid-range estimate.
** Based on MBTA operating costs: (1.32*$24.20*hours) + (1.06*$1.02*miles).
*** @ $0.38 average fare, based on Central North routes.
**** Level of service implicitly assumed in demand estimation.

Central North Bus	ALTERNATIVE ROUTES PERFORMANCE AND SERVICE SUMMARY WEEKDAY	CTPS
Technical Memorandum KHQ 10-30-87		TABLE 3

For perspective, the Porter Square routes would perform well below all Central North bus routes and the Harvard routes would be just below Route 85, Spring Hill to Kendall Square, and similar in boardings effectiveness to Route 90, Wellington to Davis Square. The Harvard routes would perform more like some of the cross-town-like routes in the South Shore, such as 217, Wollaston to Ashmont, and 245, Quincy Center to Mattapan.

8 Conclusions/Recommendations

At the request of the MBTA Service Planning department, the logistics, demand and performance associated with four alternative cross-town routes through Somerville were analyzed. There are potentially serious physical constraints to providing such service. Field observations indicate that the problems may be surmountable, but qualified MBTA personnel would have to make such a determination.

Assuming it could be physically accommodated, ridership on a cross-town route of the type analyzed would be lower than that on most other routes in the same area. Performance, in turn, would also be lower. A cross-town route to Harvard or Porter Square would make travel more convenient for some current transit riders, who would make up the bulk of ridership on a new route, but would not attract large numbers of additional riders.

It is recommended that a cross-town route of the type analyzed be dropped from consideration for now. Its relative performance, combined with an operating environment that would be difficult at best, make such a route difficult to justify. In the future, however, as Cambridge grows in employment, and as traffic and parking there becomes more onerous, a cross-town route might be justifiable.

Moreover, a longer cross-town route connecting Somerville and Cambridge to the Boston University/Fenway areas of Boston might be more sensible than the more limited routes described in this memorandum. In fact, the MBTA and its consultants are currently studying options for improving inner-area circumferential transit, and improved bus service is one of the alternatives being studied.[4] It is possible that the study could result in a circumferential transit service being implemented that would include Somerville and Cambridge and that would serve, among other objectives, those of the cross-town routes analyzed herein. Therefore, any decisions

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[4] The "Circumferential Transit Feasibility Study," being conducted by TAMS and others for the MBTA, is to be completed in early 1988.

regarding more cross-town service for Somerville should await that study's results.

If a Somerville-to-Cambridge cross-town route is considered for implementation now, a Harvard Square alternative is more sensible than a Porter Square alternative. A Harvard Square route would perform better, serve more people and provide connections to more transit services.

Attachment A - Demand Estimation Method

1. Define Market Area: The market area for each alternative was defined as one-quarter mile on either side of the alignment. Each alternative was plotted on a census tract map and any tract falling partially or wholly within a quarter-mile of a route was deemed to be in the route's market area.

2. Estimate Internal Trips:

a. Using U.S. Census Journey to Work data, a matrix of tract-to-tract transit work trips was developed for those tracts within the market area of each alternative.

b. Using the above maps, the portion of a census tract included in the half-mile wide corridor of an alignment was estimated visually.

c. Each cell in the matrix was factored by the percentage of the origin tract deemed to be within the market area. Each cell was then factored a second time according to the portion of the destination tract deemed to be within the corridor. The resulting factored matrix represented transit work trips with both trip ends in the market area. These were assumed to be the base pool from which many riders of a new route would be drawn.

d. Using maps and schedules of existing MBTA routes and much judgement, the percentage of each tract-to-tract trip interchange that would be "captured" by the new route was estimated. This percentage varied from tract to tract depending upon the degree to which the alternative route, operating on similar headways, represented "better," more direct service than existing routes. In most cases, since a cross-town route would, by definition, serve the targeted market better than existing services, most or all of the people in the matrix were "pulled off" existing routes and loaded on to the new one. All such captured trips in the matrix were then summed and the resulting figure represented the latent internal work trip demand for the new route.

e. Using factors developed from surveys of bus patrons in Cambridge and Somerville (Central North Bus on-board survey questionnaire, developed and administered by CTPS, January 1984), the internal work trip figure from above was expanded to include an estimate of non-work trips that would be "captured" from existing bus routes. Fifty percent of the

patrons on the Porter Square alignments and 60 percent on the Harvard Square alignments were assumed to be work-trip makers.

f. Using the rough rule-of-thumb that two-thirds of the ridership on a new transit route will consist of existing transit users, the "captured" internal trip market was factored up to represent the total internal trip market of existing and new transit riders.

3. Estimate and Incorporate External Trips: In this step, the internal trip market was factored up to include patrons who would have one or both trip ends external to the half-mile wide cross-town corridor. The factors used were developed from the same survey data referred to above. Based on selected use of these data, it was assumed that 60 percent of the riders of each alternative would be making external trips (accomplished by their transferring from the route to the Orange or Red Line or to another bus route). The resulting figure represented the total estimated market for the cross-town route. The figure was converted into two-way passenger trips and is presented in Tables 2 and 3 of the memorandum.

4. Perform Sensitivity Analysis: All of the factors applied to the initial matrices of internal transit work trip-makers were varied within what seemed to be reasonable limits. The results, termed lower-bound and upper-bound estimates, appear in Table 2 of this memorandum.

Taking into account differences and similarities between the alternative cross-town routes tested and nearby existing routes, the demand estimates seem to be reasonable.

4. Employ Alternative Demand Estimation Method: As a check on the above results, an alternative approach was attempted, but with mixed success. A route-level multivariate regression model, based on data for a handful of Somerville and Cambridge routes, was specified and calibrated in several forms. When applied to the alternative alignments, one or two forms of the model predicted ridership in the same range as that predicted using the above-described method. However, because the form of the "best fit" models did not conform to intuitive expectations, the method was abandoned and the results are not presented here. With more data and time, this approach could result in a valuable service planning tool for use throughout the system.